Wireless Sensor Network for Monitoring Rowing Performance, Safety and Athlete Fatigue for Training

Arnout Hilhorst, Maarten Visscher, Devi Darshini Manickam, Yimi Zhao and Kas Burgers
{a.t.h.hilhorst, m.h.visscher, d.d.manickam, y.zhao1, k.k.j.burgers}@student.tue.nl

***Abstract*—Rowing is a sport which has many training sessions. An instantaneous monitoring of the training is beneficial to the athletes as the coach can guide them as they practice. For performance evaluation during training, a rowing boat might be equipped with sensors to measure speed, disturbances, location of the boat and pressure on the water. Also, each individual rower might have a heart rate monitoring sensor on their body. These sensors should transmit their data to a base station to allow a coach to track the performance and health. Also, the same can be used to track if any other boat is nearing. As a boat is moving on the water, this information is needed in real-time which requires a wireless communication protocol to enable the heart rate sensors and the pressure sensors to communicate with the main device in the boat and for the main device to communicate to the coach and nearing boats. A simulation is made to show and explain a sensor network which satisfies the constraints of the quality of service requirements. A overview of the network is given, with the scheduler and MAC protocol used and the sensors which can be used to create the network.**

***Keywords*—Rowing, Athlete, Performance, Pressure Sensor, Heart Rate Sensor, Accelerometer, IEEE 802.15.4, Serial Peripheral Interface, Time Division Multiple Access, Reduced Function Devices, Contention Free Period, Cooja, Contiki.**

I. Introduction

Rowing is similar to an endurance sport, like cycling, triathlon or running. This means that a lot of training times have to be on the long side. To make sure the athlete does not overextend him or herself a lot of monitoring needs to take place while training. For the monitoring of the athletes one can look at the heart rate, the acid build-up in the muscles or the amount of oxygen used by the muscles. When looking at the rowing stroke, the most speed can be accomplished while rowing simultaneously and making sure the power in a stroke is done in the most efficient way. To measure the efficiency of a rowing stroke the pressure per centimeter stroke has to be measured, together with the angle of the stroke in retrospect to the boat and the amount the boat gets disturbed each stroke. To disturb the boat as less as possible a rowing crew has to row as synchronized as possible.

When looking at the bigger crews, one can see a person who is not rowing. This person is called the cox or the steer. This person steers the boat and is in command on the boat. A problem for the cox is that he or she is a person who sits behind the rowers. Because of this the cox cannot look in front of the boat to see if anything is nearing. This is not a problem when racing but while training this can be a problem. For example, in Eindhoven, the canal is not that wide. So, a sensor which alarms the cox when a boat is coming the other way is really helpful when trying to avoid crashes.

While coaching the rowers, an overview of the vitals of the rowers and the power produced can be super helpful. This enables the trainer and rowers themselves to check if they are still in good shape and are following the training regimen, or to see if a rower is not giving it their all. The coach is normally cycling at the edge of the water canal or rowing in a little motorboat behind the rowing crew.

II. Scenario

Some rowing clubs have a lot of space to row or even an Olympic course to row on. For the clubs which have a lot of money, an indoor rowing setup is the best option for the really technical training. These setups are really expensive but gives a lot of information about the pressure on the water and the way people are moving. This can then be translated to a real rowing boat. The situation for which this system is made is a small canal in which just barely two boats can pass one another, because of which it is hard to see boats coming in the opposite direction. With a cycling lane for the coach next to the canal, the range of the system doesn't need to be as long. Everything is within 100m of the boat. A coach can be training with multiple boats so it would be best if the system could handle multiple boats at once which are in a range of about 500m to one another. The coach can cycle next to the boats on the shore, so that coach has a real time information on the training system through a screen. This way the coach can give fast feedback to the rowers.

III. Literature Survey

The main objective of the paper is to monitor the athletes and send an analysis report, on the performance of rowers and the boat, to the coach in real time. Along with this, the data collected is also used to send a signal to any other boat nearing. The information about the speed, the location, the pressure on the blade, the mobility of the boat and the heart rate of rowers are collected for the analysis. In [9], the speed and the location is found using a combination of the output from GPS and accelerometer. This information can be transmitted to the coach as well as the nearing motorboats to ensure safety. In order to acquire the effectiveness of the rowers, the force they exert on the blades can be used. Various sensors used to monitor the rowing technique is explained in [17]. From this, it is inferred that the pressure sensor can be used to find the applied power on the blade. We found that a load cell would suit the application which is explained in [13]. In addition to the pressure sensor, a heart rate monitoring device can also be used to analyze the performance of the athletes. A method has been advanced in [5] where the heart rate is monitored using a wrist worn device. Also, it has a wireless communication system which sends the heart rates of all rowers to the coach for monitoring. All these sensors have to be connected to a central controller for processing and the processed data has to be sent to the coach and nearing boats. To facilitate the data transfer, a wireless communication network is required. Considering the short range and the power requirements, it has been concluded that the IEEE 802.15.4 LR-WPAN protocol can be used for data transfer. In [16], a GUI is developed to monitor the rowing race from the control room. This can be modified to provide a GUI for the coach to monitor the rowers. By combining above said technologies, the system is developed in the following way to meet its objective.

The main difference of the proposed project from the existing models is that it is used for analysing the training period of the rowers. Most of the present systems are used for monitoring rowing races and not for training. Training being an important part in rowing, the proposed system aims at monitoring various aspects of training as mentioned above. It also provides real time data to the coach as well as any boats nearing.

IV. Sensors

A short explanation is given for each sensor. In the next part a choice is made for a specific sensor and after this a justification is given for the rates at which the data is send.

A. Heart Rate Sensor

Most heart rate sensors that are currently commercially available use either the Bluetooth Low Energy protocol or ANT+, where ANT+ is a proprietary protocol similar to Bluetooth 4.0 which enables low-power communication in a relatively short range of around 30 meters. An example product [15] allows communication using 5.3kHz, Bluetooth and ANT+, where 5.3kHz is used by treadmills and other fitness devices to show and possibly react on the heart rate.

The paper by Beach et al. [5] presents a proof-of-concept wrist worn heart rate monitor using ECG which uses wireless communication to make its sensor data available to IoT infrastructure. Similar to the commercial products Bluetooth Low Energy is used here as well, whereby the sensor broadcasts its data periodically and unidirectional. The advertisements can be captured by receivers around the device, and localization of the device can be achieved if multiple receivers capture the advertisement, using the signal strength. Battery usage depends on the period of advertisements.

While the cases in literature and industry presented here all use protocols with mesh networking like Bluetooth, in our application that is likely not needed, only a network with star topology is necessary. For this reason, we will use the IEEE 802.15.4 protocol which has less overhead and therefore less power consumption.

As fluctuations in heart rate are not important, the data only has to be send with a minimum of once per second and with a maximum of around once per five seconds. The most important part is that the average heart rates are in the zone which is planned for the specific training. The range of 30 meters is long enough because the biggest boats are 18 meters long and if a base station is made in the boat this should be in the range from the wristbands.

B. Pressure Sensor

To find a feasible pressure sensor which measures the power on the blade, one needs to know what the maximum applied force will roughly be.

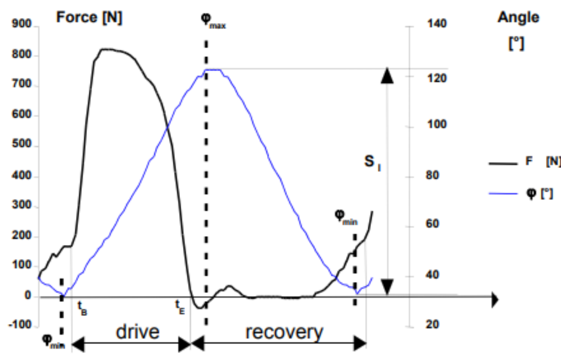

Figure 1: Overview of force on the blade [12]

Looking at Figure 1, it can be seen that the maximum applied force is around 800-900 newton for a normal stroke [12]. The absolute maximum researched was 3230 watt [8]. A pressure sensor which can handle this pressure is needed for our simulation.

We chose to use the 'AWL Light Loadlink' load cell, which can withstand 10 tons. This limit is way over our maximum, but we chose this sensor because it already has wireless communication embedded. The sensor is precise and only has a 0.25 % possible offset. The input voltage varies from 11V to 28V. The transmitted signal can be send over the range 2425 - 2430 MHz.

The data for the pressure sensor has to be received frequently because the pressure is important at almost every part of the stroke. The graph in which someone can show the part of the stroke at which the pressure is the highest is important together with the angle at which the pressure is put on the blade. This way the coach can see if the rowers push at the correct time and in the same timing. Because a rowing stroke takes approximately 0.7 seconds, the sampling rate has to be more than 10 hertz [12].

C. Accelerometer

An accelerometer can be used to measure the speed and the disturbances in a rowing boat. This can be used to check if the movement of the rowers is in sync and if the boat moves smoothly. At its peak a boat moves at 25km/h which can be easily measured by most accelerometers [11]. Accelerometers use the piezoelectric effect which consists of microscopic crystal structures that gets stressed when they are under accelerative forces [7]. This causes a voltage to be generated. This voltage then depends on the amount of gravitational force the accelerometer is under.

There are two types of accelerometers, the first is the analog and the second is the digital. The analog meter outputs a continuous voltage proportional to the acceleration. For example, 2.5V is 0g, 2.6V is 0.5g and 2.7V is 1g, etc. The digital accelerometers use pulse width modulation (PWM) for the output. This means there is a square wave of a certain frequency and the time in the signal in which the voltage is high is in relation with the acceleration.[7]

The choice of accelerometer depends on four factors, the range, the interface, the number of axis and power usage. The range for the accelerometer must be at least +/- 2g [9]. The interface should be a digital one or the PWM as output for easier data transfer. The number of axis have to be three because the disturbances in the rowing boat have at least two axis. Also, if the accelerometer is used along with the GPS, then the least amount of axis is three [9]. The power usage is not stressed because this is the only sensor added to the on-board module. The paper of Hermsen [9] suggests the use of the MMA8452Q Accelerometer Breakout. The ADXL345 is the upgraded version of a competitor with more bonus features which can be used to upgrade the system with more rowing related data. So the final choice comes to ADXL345 [18].

The accelerometer data is also quite specific and has to be sent at a high rate to see where the boat gets disturbed in the stroke. This might be more at the front of the stroke, the point at which the rowers start rolling up the slides and at the end of the stroke. For the rest of the stroke the disturbances are less important. As the rowing stroke takes only 0.7 seconds, the sampling rate of the measurements should be < 0.05 seconds between samples [12]. This is important to distinguish the disturbances from the actual acceleration.

V. Quality of Service Requirements

The life time of the system should be around the maximum time a crew trains on a single day. This should be around four hours in total, two training of around 90 minutes with an added hour, if the training are longer or the battery gets worse (Battery life). Since the battery life need not be long, the batteries should be rechargeable. The most important part of the system is the fact that the coach should be able to get out of range of the boat and back in it and the data should refresh itself on the coaches screen (Reliability, Stability). So for reliability purposes, the boats should be sending out data in a continuous manner and the receiving end should be open to receive a new component. The latency isn't the most important as long as the data per stroke is the same for each rower and the corresponding data from the accelerometer is connected to the pressure sensor (Latency). The heart rate data can be send separately because this only has to update every five seconds (Data Sampling rates). If at a later stage the coach could add multiple boats this should be a good added feature on the system, so the coach can have the data of three single boats (skiff's) for example (Expandibility, Futureproof). In Appendix B, the full table can be found in which for each requirement a quantative or a qualitive value is given. These can be used to check in the evaluation if the network will suffice with the quality of service requirements.

VI. Network Architecture

The chosen network architecture will be explained together with the reasoning for the protocol. A section is added for the beaconing to other boats to warn the cox.

A. Communication Module and Position

To send the data to the shore we need a module to send the data. This can be done by various means like WiFi, ZigBee or Bluetooth. After researching the IEEE 802 standard, which is a family of IEEE standards dealing with local area networks and metropolitan area networks, we saw that a combination between an IEEE 802.15.4 standard and a broadcast method is often used. One of the common ways to establish a communication network is to use the concept of networking layers. Each layer is responsible for certain functions in the network. The layers normally pass data and commands only to the layers directly above and below them [6].

B. Overview of the Architecture

Each boat has 16 wireless sensor nodes, 8 heart rate sensors and 8 pressure sensors, which are low-power devices. As the devices need to be energy efficient, we put a base station inside the boat for the sensors to connect to. This leads to a simple topology which has the advantage of being energy efficient because no routing needs to be implemented and the base station can provide contention-free medium access, reducing the risk of collisions and re-transmissions. There is a separate node for the coach which also connects to the base station to retrieve the sensor data. An overview of the nodes is given in Figure 2.

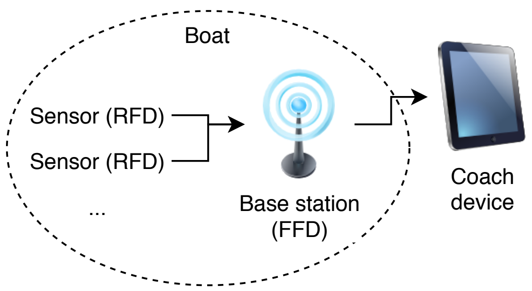

Figure 2: Each boat has a star topology network, the sensors and the coach device connect to the base station.

C. Micro-controller

The micro-controller is required for collecting all the data, processing and transferring them. It provides an interface for the Arduino MRF24J40 IEEE 802.15.4 2.4 GHz RF Transceiver. Also, the AWL Light Loadlink Load Cell is used along with a standalone receiver interface AWL-RI, which provides the output via USB. An USB Shield can be used along with the micro-controller for collecting this data. The LR-WPAN module and the USB shield require Serial Peripheral Interface (SPI) for connecting with a micro-controller. Considering these requirements, the controller that can be used for this project was found to be Arduino Mega 2560 REV3. It has 4 serial ports which can be used for interfacing LR-WPAN and the USB shield. It also has a low operating voltage of 5V.

D. MAC Layer

IEEE 802.15.4 defines robust radio physical (PHY) and medium access control (MAC) layers [2]. Depending on the application requirements, an IEEE 802.15.4 LR-WPAN operates in either of two topologies: the star topology or the peer-to-peer topology. One use of the peer-to-peer communications topology is the cluster tree [4]. The paper by Hossein et al. [19] states that the cluster-based networks like Figure 3 can cover the targeted area and provide the system requirements.

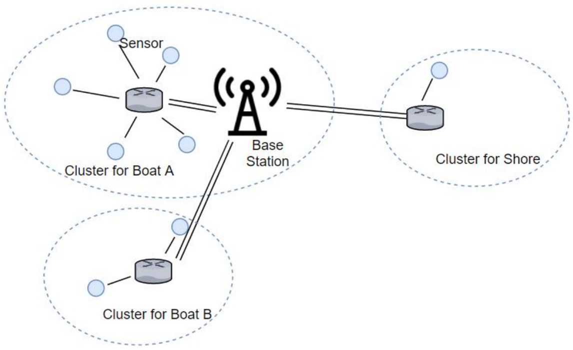

Figure 3: Cluster based wireless sensor network.

M. Aminian et al. [3] noted among various existing MAC protocols, it is possible to use the Time Division Multiple Access (TDMA) protocol for media access in the system because there is a constant number of nodes between sensors and the cluster head node. TDMA divides the channel into individual time slots, which are then grouped into frames. In each time slot, only one node can transmit. TDMA is intrinsically energy-efficient. A sensor node only needs to turn on its radio during the time slot where it needs to send data.

IEEE 802.15.4 is suitable for our application because it is simple and does not implement routing, which we don't need due to the star topology. As a result it is energy efficient for our sensor nodes, which are reduced-function devices (RFDs) in IEEE 802.15.4 terminology. The base station inside the boat acts as PAN coordinator. The protocol requires certain configuration which we discuss here.

a) Beaconing: The protocol can be set to beacon-enabled or beacon-disabled mode, which specifies whether beacons are transmitted periodically or only upon request. A beacon is always sent at the start of a superframe and is necessary for the sensors to be able to transmit their data. In our application the sensors need to transmit their data periodically, therefore beacon-enabled mode is applicable for us. The period is determined by the data rate that we want to achieve, which is in our case 0.05 seconds or 20 hertz.

- *macBeaconOrder*: the period for beacon transmissions, a value of 1 results in a rate of approximately 0.03 seconds when using 2450 MHz [10].
- *macMaxCSMABackoffs*: we use the default value of 4, we try to avoid contention based medium access for energy efficiency, therefore this setting is less applicable.
- *macMinBE*: backoff exponent, only applicable for contention based access, therefore we use the default value of 3.
- *macSuperframeOrder*: the active period, which is less or equal to *macBeaconOrder*. We will use a value of 2 or 3.

b) Medium Access: As our sensors provide data every superframe, we can use the contention-free period (CFD) to allow the sensors to transmit their data without the risk of overhead from collisions.

E. Rolling Boat to Shore Station

A cluster based rolling boat to shore station communication system provides the opportunity to let the coach remotely monitor the athletes' performances and the boat's real time position. In this system, an IEEE 802.15.4 network can be used to collect data from various sensors connected to the athletes and the boat [6]. The cluster head is a wireless node in the boat which is in charge of collecting and packaging the arrival signals from other sensors and send them to the base station. This node attaches on the boat and it works with battery. Each coordinator node is identified by a unique ID which is used to identify each boat in the network [3].

VII. Simulation Tools

The simulation tool chosen is Cooja in combination with Contiki OS. We have chosen this tool because it is compatible with the 802.15.4 protocol as can be seen in [1]. The tools were provided by course 5LIC0 (TU/e course code). Cooja runs on Ubuntu Linux which made it necessary to install a virtual machine (VM) to run the tool. The used VM is provided by the course, "Electronic Systems - Computation Virtual Machine", from the TU Eindhoven. The Matlab Simulator was also evaluated because of prior knowledge, however because the Cooja toolset is developed especially for simulations on networks and the course advised to use this tool the decision was made to use Cooja and Contiki OS.

VIII. Implementation Plan

The desired system should be tested which can be done by making a digital representation of the system. Every piece of hardware will be implemented in the Cooja simulator. The implementation will be started by making a node for each sensor.

A. Sensor Node

This node consists of a slot number for the TSCH scheduler and its process, the broadcast to sender process so that the node can make a connection to the main node in the boat. It has to be able to receive a broadcast from the center node and handle the connection towards this node. Then, it starts sending the sensor data, for example, the heart rate data. This data gets sent in a message to the center node alongside a sequence number. The center node can distinguish different sensor nodes based on the sender address. In the implementation, the starting value for the heart rate sensor is taken as 110, a standard value. It is made to change by adding or decreasing one randomly. This is similar in real life but, over a longer training the heart rate will rise. In real time sensing, the heart rate will be sensed by the sensor and will be sent to the main node. The heart rate node will send the data every second to the center node in the boat which qualifies with the quality of service which is stated.

The pressure node is made to work similar to the heart rate node. The pressure also begins with a starting value and will be increased or decreased. In real time, the change in value will happen in 0.7 seconds to simulate a rowing stroke and will be zero for the next 2 seconds when the rower takes the blade out of the water. This data will be sent with a sampling rate of 0.05 seconds, so that the coach node will be able to create a graph of the power in the stroke.

B. Center Node/Base Station

The base station is created by connecting all the sensor nodes to one sink node. This sink node will create a network by sending out a broadcast and if a signal is sent back from the sensor nodes, the node will be connected to the base station. The sink node in the base station will receive all messages from the sensors and will pack the pressure sensor data and send it to the next recipient. In the base station, the accelerometer will also be added to the packaged data. The accelerometer, as mentioned, has three axis. This implies that three values will be generated and these will range between -240 and 270. These values together with the sensor values can be used to calculate the disturbance and the speed at which the boat is moving. As this data will also be generated at a rate of 0.05 seconds per data point, the base station will send this information to the coach in packages and send the heart rate data immediately through to the coach. The base station will keep on sending a beacon to keep every node connected and to reconnect if the coach sink is out of range. This beacon is sent with its value so another sink can see if a new station enters the range. This will trigger a LED light in the boat, so the cox will know that a different boat is close.

C. Coach Sink

The mote for the coach is also a Sky mote with the basic build-up of a sink. The assumption was made that the GUI and the rest of the application can be made at the background of the sink so this did not need to be simulated anymore. The data is not wireless anymore at this point. A sample GUI is made and shown in Appendix C. The coach sink will print out every message which was received and will update the message shown with each new value or new package which arrives.

D. Protocol and Scheduler

The scheduler used is TSCH, Time Slotted/Synchronized Channel Hopping. This is a method for shared medium networks. It uses low-power devices, and it uses diversity in time and frequency to provide reliability to the upper network layers. It uses time slots to send the data and to turn off the radio when it is not used. This is done to lower the power usage of the system and to ensure the least amount of interference. This also helps with preventing the multi-path fading effect because, as the network exists on multiple sensors in close proximity, the range of the fading is not the most important, however the chance of the ‘ghosting’ effect is lessened. The reason is, as the TSCH can use all of the 16 frequency channels of the 2.4 GHz, the network capacity will increase [14]. The TSCH will use an Absolute Slot Number (ASN) to keep track of the number of time slots which have elapsed since the start of the network. With the initializing of the nodes and sinks, the simulation will initialize a schedule for the TSCH and makes sure to broadcast the nodes and schedule them in the TSCH. The time slots, made in a dedicated manner, are used to establish a link to the nodes and to make sure the sending of information will not collide with each other. To keep the timers consistent, the nodes and sink will all have an internal clock which keeps track of the ASN. The time synchronization is done with a frame based synchronisation method [14]. The full network is based on the schedule prompted by the base station node.

IX. Evaluation

A. Evaluation Plan

For the sensors, an evaluation set of data will be provided. The new data will be randomly generated values with boundaries as expected in real time sense. The system will be evaluated by checking our expected output with the output from the simulation. The expected output is based on Section V and personal experience from the authors with rowing. It is also based on the requirements as stated in the Network Architecture, Figure 4, which is discussed as follows. It is required that the accelerometer and the pressure sensor values must have a maximum data rate of 0.05 seconds. For the heart rate sensor, the rate must be between 1 and 5 seconds. The maximum range of the coach from the boat is 100m. So, it is required that, when the coach moves out of the range and then re-enters the communication range, the system must be able to recognize the coach and re-establish the connection. Thus, the proposed system is simulated in Cooja and then the results are evaluated based on the points mentioned above.

B. Evaluation Results

The system is simulated with one base station node, one coach device node, eight heart rate sensor nodes and eight pressure sensor nodes. The simulated system delivered the required output with some extended lag. It was calculated that the average rate of pressure sensor (all eight sensors) and accelerometer data to the coach device is 0.395 seconds, measured over a period of 52 seconds. Also, the average rate of all the heart rate values to the coach device is 1.971 seconds, calculated over a period of 60 seconds. The re-connectivity to the coach device when it moves in and out of the 100m range is achieved, i.e. whenever the coach device node is taken out of the connectivity range and then back into the range, a connection to the base station node is successfully established. In real time, this can be related to the instance where the coach may cycle slowly for some reason. Also, the system is designed such that whenever a pressure sensor or a heart rate sensor is dysfunctional, the value is taken to be zero and the same value is sent to the coach. The only part that was unachievable was the warning system to the nearing boats.

X. Conclusion

Thus, the system developed can be used for the real time monitoring of training sessions of the rowing sport. The system is simulated based on the real time constraints which can be readily converted into a hardware based network for actual monitoring of the training. With the help of the sensor data, the coach can get information about the performance and health conditions of the rowers and also about the movement of the boat. Using this information, the coach can guide the trainees efficiently and achieve good results. With few more elements added to the system, as discussed in Section XI, the efficiency can be increased.

XI. Future Work

The advancement of the project would be developing the GUI for the coach as shown in Appendix C. A cloud connectivity can be incorporated, which will help the coach and the trainees to review the data later. For a follow-up project, it might be possible to do tests with real hardware components and see if our code and design will work in real life.

A future step for our project would be adding a GPS into the base station, next to the already implemented accelerometer, which can increase the accuracy of the speed and position data. Also, currently the coach can monitor only one training boat. It can be extended such that the coach can monitor two or more training boats simultaneously.

References

[1] A.Mileva A. Velinov. "Running and Testing Applications for Contiki OS Using Cooja Simulator". In: *International Conference on Information Technology and Development of Education* (2016).

[2] ZigBee Alliance. "ZigBee wireless sensor applications for health, wellness and fitness". In: *White paper. March* (2009).

[3] M Aminian and H Reza Naji. "A hospital healthcare monitoring system using wireless sensor networks". In: *J. Health Med. Inform* 4.02 (2013), p. 121.

[4] IEEE Standards Association et al. "IEEE Standard for Low-Rate Wireless Networks". In: *IEEE Std* 802 (2016), pp. 4–2015.

[5] Christopher Beach et al. "An ultra low power personalizable wrist worn ECG monitor integrated with IoT infrastructure". In: *Ieee Access* 6 (2018), pp. 44010–44021.

[6] Shahin Farahani. *ZigBee wireless networks and transceivers*. Newnes, 2011.

[7] Friedel Gerfers et al. "Sputtered AlN thin films for piezoelectric MEMS devices-FBAR resonators and accelerometers". In: *Solid state circuits technologies* (2010), p. 333.

[8] U Hartmann et al. "Peak force, velocity, and power during five and ten maximal rowing ergometer strokes by world class female and male rowers". In: *International journal of sports medicine* 14.S 1 (1993), S42–S45.

[9] Harm Hermsen. "Using gps and accelerometer data for rowing race tracking". In: *Dept of Artificial Intelligence* (2013).

[10] Joe Hoffert, Kevin Klues, and Obi Orjih. "Configuring the IEEE 802.15. 4 MAC layer for single-sink wireless sensor network applications". In: *Washington University in St. Louis* (2005).

[11] Daniel A James, Neil Davey, and Tony Rice. "An accelerometer based sensor platform for insitu elite athlete performance analysis". In: *SENSORS, 2004 IEEE*. IEEE. 2004, pp. 1373–1376.

[12] K Mattes. *Diagnostic of rowing performance and technique to optimise the rowing technique*. 2013. URL: http://www.worldrowing.com/uploads/files/Diagnostic_of_rowing_performance_and_technique_to_optimise_technique_training.pdf (visited on 09/18/2020).

[13] Ivan Muller et al. "Load cells in force sensing analysis–theory and a novel application". In: *IEEE Instrumentation & Measurement Magazine* 13.1 (2010), pp. 15–19.

[14] Farhan Naeem. "Dynamic Centralized Scheduler for Time-Slotted Channel Hopping Wireless Sensor Networks". MA thesis. Department of Mathematics and Computer Science EIT Digital Masters in Embedded Systems: TU Eindhoven, 2016.

[15] *Senz Sports accessoires*. URL: https://senzsports.nl/accessoires (visited on 09/21/2020).

[16] Nuno D Simões et al. "ZigBee/GPS tracking system for rowing races". In: *2011 IEEE EUROCON-International Conference on Computer as a Tool*. IEEE. 2011, pp. 1–4.

[17] Bernd Tessendorf et al. "An imu-based sensor network to continuously monitor rowing technique on the water". In: *2011 seventh international conference on intelligent sensors, sensor networks and information processing*. IEEE. 2011, pp. 253–258.

[18] YUAN Xi et al. "Three-axis digital accelerometer ADXL345 and its application in SINS design [J]". In: *Electronic Design Engineering* 3 (2010).

[19] Hossein Hadaidian Nejad Yousefi, Yousef Seifi Kavian, and Alimorad Mahmoudi. "A markov model for in-

vestigating the impact of IEEE802. 15.4 MAC layer parameters and number of clusters on the performance of wireless sensor networks”. In: *Wireless Networks* 25.7 (2019), pp. 4415–4430.

Appendix

A. Network Architecture Overview

Figure 4 shows an overview of the nodes in the network.

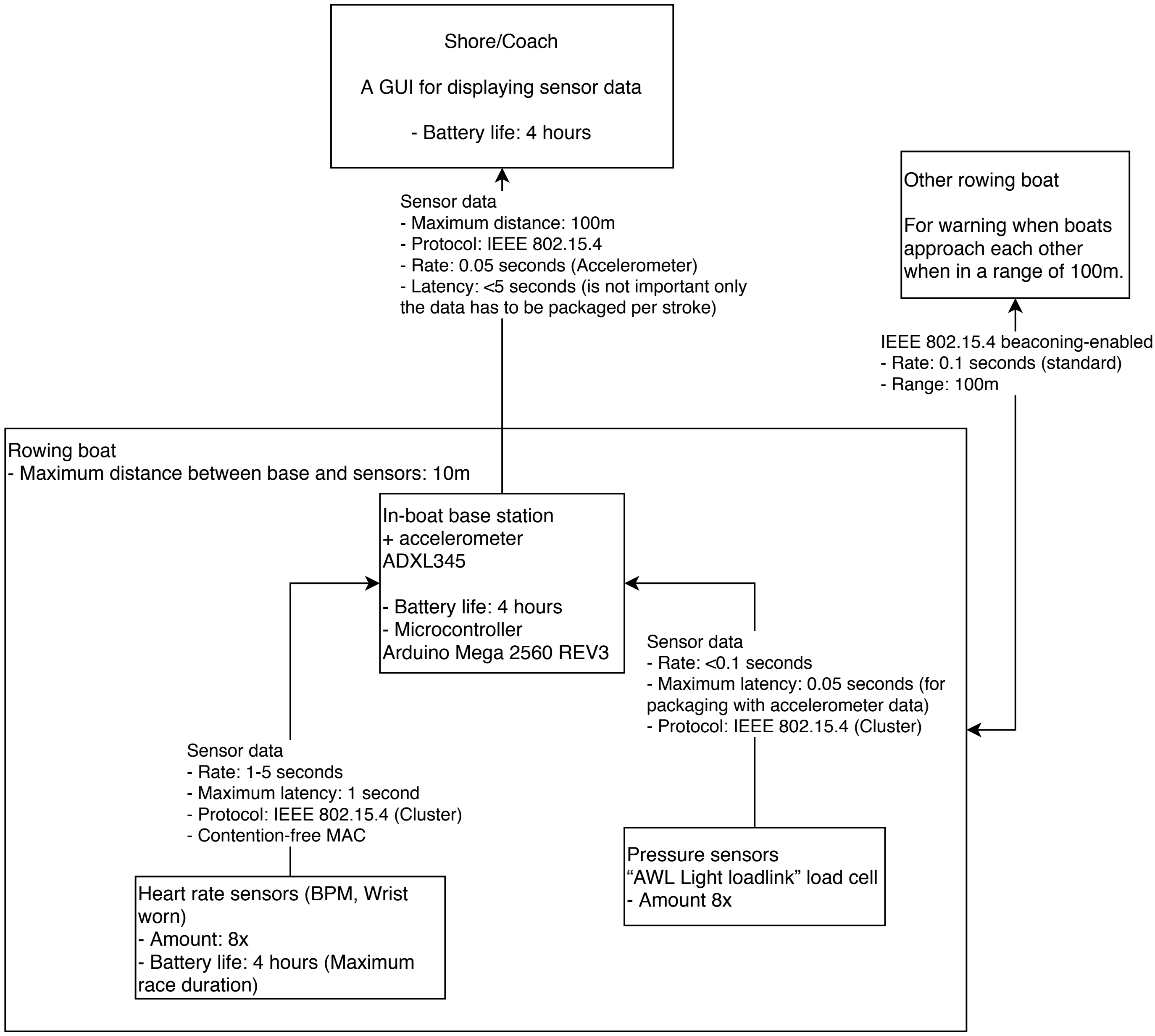

Figure 4: Overview of the network.

B. Quality of Service Table

In Table I the results obtained when evaluating the requirements on the wireless sensor network are shown.

Requirement	Quantitative	Qualitive	Remark
Battery life	>4 hours		Rechargeable
Data sampling rates 1) Heart rate 2) Pressure 3) Accelerometer	 <1 sec <0.05 sec <0.05 sec		Make graph for stroke
Beacon Range	<100m		Safety for boat by warning cox
PRR	>70%		Least interference and collisions
Reliability/Dependability		High fault tolerance, nodes failure possible and coach can leave the network range	
Environment of Deployment		Dedicated topology of nodes and waterproof	
Latency	<3 sec	Pressure data is updated before sending package	
Constraints on sensors		Wearable heart rate sensor and oarlock pressure sensor	
Expandibilty		Addition of new boats to network	
Futureproof		Cost reduction, energy consumption, miniaturization and weight minimization	Sorted by importance

Table I: QoS requirements.

C. GUI for the Coach

The Figures 5, 6, 7 show the Graphical User Interface (GUI) for the coach. Figure 5 is the home page for the coach. When the Add Participant option is chosen, the coach reaches the page shown in Figure 6. When the Participants List option is chosen, the coach reaches the page shown in Figure 7.

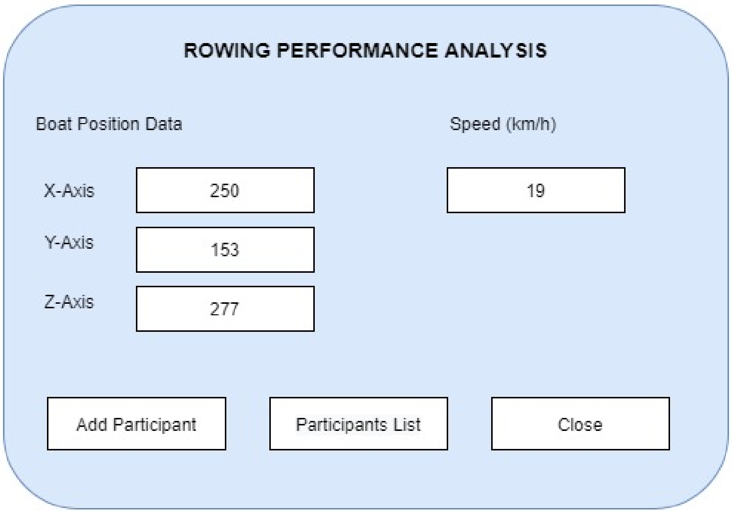

Figure 5: GUI home page.

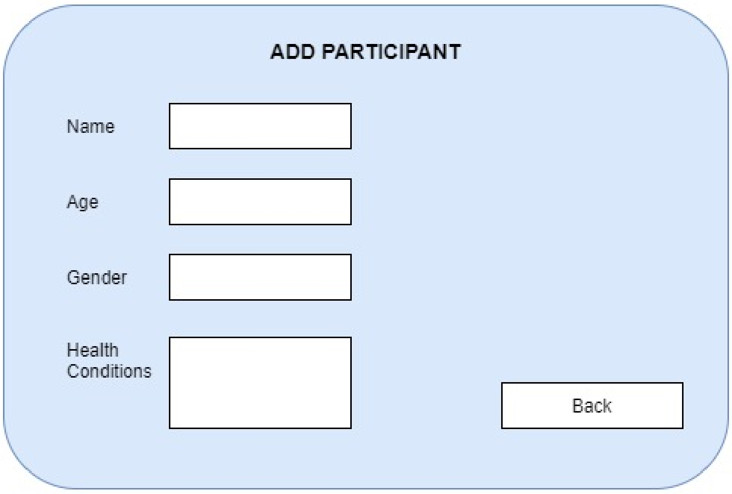

Figure 6: GUI add participant page.

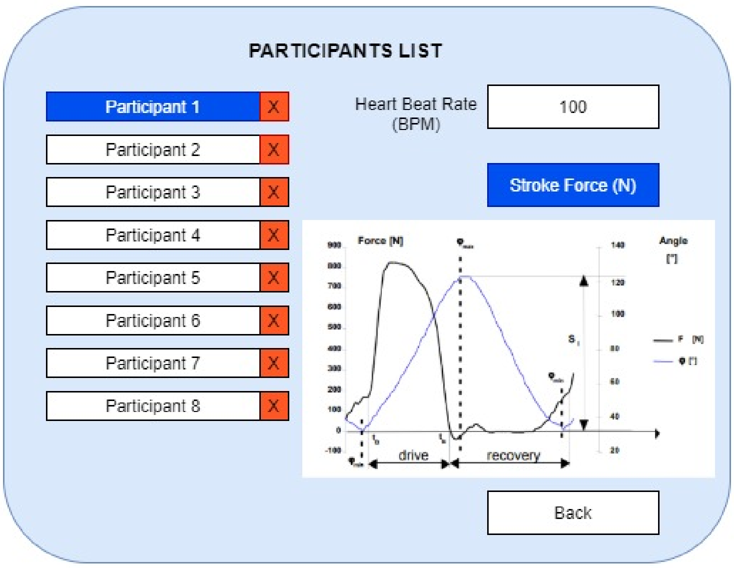

Figure 7: GUI participant list page.

D. Simulation screenshots

Figure 8 shows the network simulated using Cooja. Node 1 is the boat base station which sends the sensor data to node 2, the coach device. Nodes 3 to 10 are the heart rate sensors, nodes 11 to 18 are the pressure sensors.

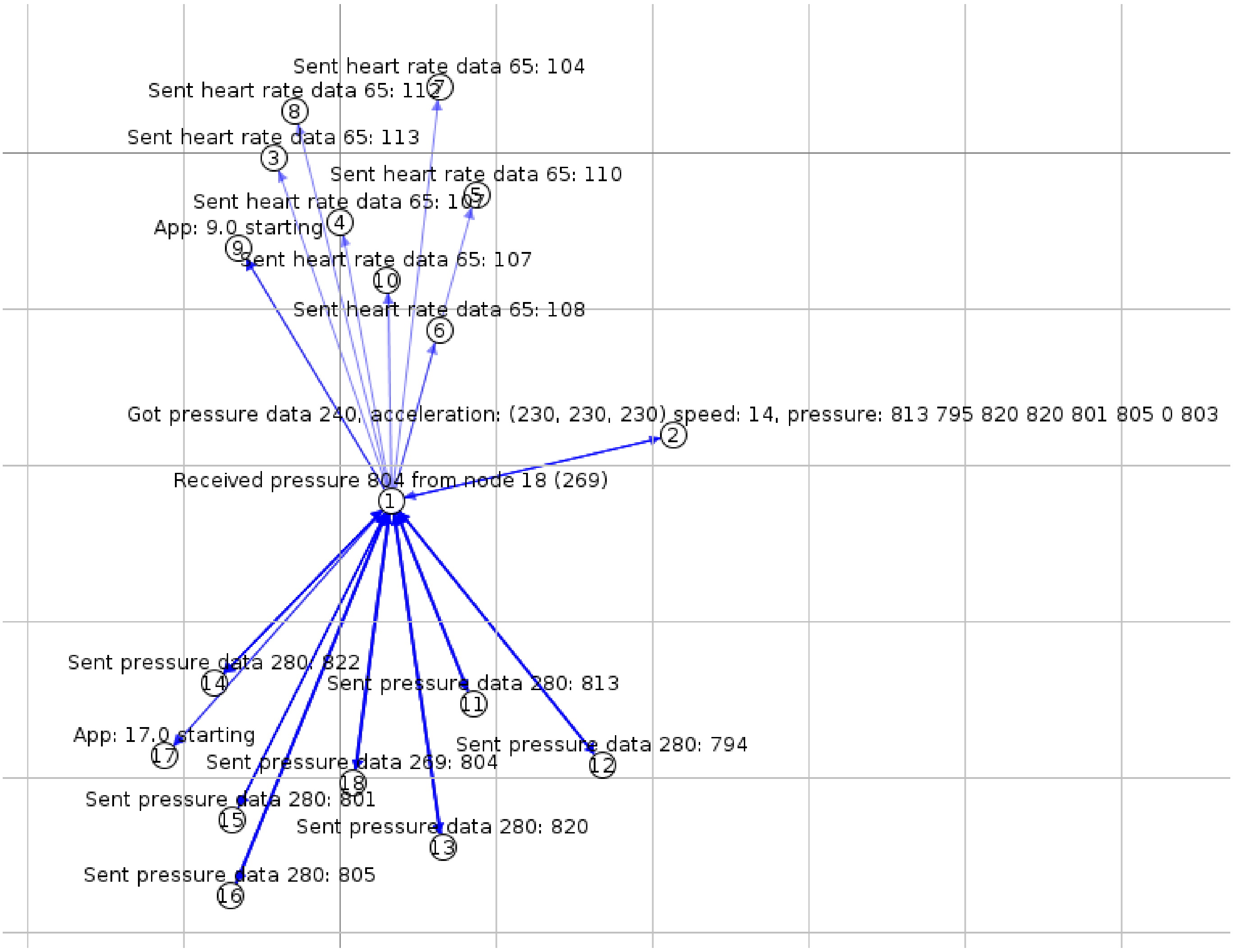

Figure 8: Network simulation in Cooja.