

Alexandra Riddell-Webster

A System to Prevent Crashes in Rowing Boats

Computer Science Tripos – Part II

Murray Edwards College

2023

Declaration of Originality

I, Alexandra Riddell-Webster of Murray Edwards College, being a candidate for Part II of the Computer Science Tripos, hereby declare that this dissertation and the work described in it are my own work, unaided except as may be specified below, and that the dissertation does not contain material that has already been used to any substantial extent for a comparable purpose.

I am content for my dissertation to be made available to the students and staff of the University.

Signed: Alexandra Riddell-Webster

Date: April 11, 2023

Acknowledgements

This dissertation owes a huge amount to Matthew Ireland, for supervising me. My UTO, Jon Crowcroft was invaluable. Thanks to Cambridge University Boat Club, in particular Patrick Ryan and Mike Taylor, for allowing me to put strange boxes on boats and for advising me on communication over water. I also thank Duncan Barnes for discussing GPS and electronics on rowing boats with me.

Proforma

Candidate Number:	TODO
Project Title:	A MANET to Facilitate Collision Avoidance in Rowing Boats
Examination:	Computer Science Tripos – Part II, May 2023
Word Count:	TODO ¹
Code Line Count:	TODO (inc. comments?)
Project Originator:	Alexandra Riddell-Webster
Supervisor:	Mr Matthew Ireland
University Teaching Officer:	Dr Jon Crowcroft

Original Aims of the Project

TODO

Work Completed

TODO

Special Difficulties

None.

¹TODO

Contents

1 Introduction	6
1.1 Motivation	6
1.2 Background	6
1.3 Related Work	7
1.3.1 Networking	7
1.3.2 Delay Tolerant Routing	8
1.3.3 Safety in Rowing	8
2 Preparation	9
2.1 Starting Point	9
2.2 Choice of Hardware	9
2.3 Requirements	10
2.4 Choice of Programming Language	11
2.5 Summary of Research	12
2.5.1 MANET	12
2.5.2 Routing	12
2.5.3 Epidemic	12
2.5.4 Media Access Control	13
2.6 System Design	13
3 Implementation	15
4 Evaluation	16
4.1 Evaluating the MANET	16
4.2 Evaluating the System	16
5 Conclusion	17
5.1 Achievements	17
5.2 Learning	17
5.3 Future Work	17
Bibliography	17
Appendices	19
A – Guide to Building a Node	19
B – Evaluation Plan	20
C – Progress Report	24
D – Project Proposal	27

Introduction

During this project I built a system to prevent crashes in rowing boats. The system is implemented in hardware, cumulating in a series of boxes that can be attached to boats. The project is split into two parts – the MANET that allows nodes to communicate a dynamic collection of known obstacles, and the application layer that warns users when they are approaching an obstacle and allows the user to add obstacles. The system will be available online, fully documented, after my graduation. This will include a ‘how to’ guide [[Appendix A](#)] for construction of a node so any rowing club can use my project as a collision avoidance tool.

1.1 Motivation

Crashes between rowing boats and obstacles or other boats injure rowers and cause equipment damage. Crashes are common – Figure 1.1 shows an eight on the Thames, having collided with Barnes Bridge at a regatta in March 2023. Some boats have coxswains, responsible for steering a boat, while others are coxless, where rowers who face away from the direction of travel are responsible for steering boats. This project is designed for use in both coxed and coxless boats.

My project has a very personal motivation, as a friend was hit by an eight while in a single three years ago, causing a severe concussion that resulted in two years of intermission from their studies.

Figure 1.1: An eight colliding with Barnes Bridge [1]



1.2 Background

There is precedent for using MANETs on rowing boats. I spoke to Duncan Barnes, part of the team behind the broadcasting and associated telemetry for the Oxford Cambridge Boat Race. They use a 15-node MANET to get the video and telemetry from the rowing boats. They also take GPS readings for the location of the boat, recording the location of the boat up to 20 times a second. Figure 1.2 shows the equipment they attached to the crews for the 2023 Boat Race.

Figure 1.2: Equipment placed on the stern of the Cambridge boat [2]



A technical challenge faced by my project was effectively utilising the small CPU on the Raspberry Pi Pico [3] to propagate messages through an unpredictable dynamic topology, with nodes that frequently move at speeds of more than 15 km/h.

1.3 Related Work

1.3.1 Networking

The Defence Advanced Research Projects Agency (DARPA) Packet Radio Network (PRNET) [4] was the first wireless data network, using store-and-forward routing over packet radios. Jubin and Tornow lay out the state of PRNET in 1987, nearly 15 years after research began on it, in their paper ‘The DARPA Packet Radio Network Protocols’. The work on PRNET fed into DARPA’s Survivable Radio Network (SURAN) [5]. The connection between the military and ad hoc networking still exists today, with MANETs used in conflicts [6], as well as autonomous vehicles [7] and disaster relief scenarios where previously existing infrastructure is destroyed [8].

The Open Systems Interconnection (OSI) model for computer networking provides an abstraction of the communications between computers. The OSI model consists of seven layers: Application, Presentation, Session, Transport, Network, Data Link, and Physical [9]. This project uses the libraries provided with hardware for the Physical and Data Link layers. It focusses mainly on the Networking layer, sending messages between nodes.

While routing corresponds to many hops across a network, medium access control considers only one. Media access control protocols control access to the transmission media to prevent collisions between messages.

1.3.2 Delay Tolerant Routing

Delay tolerant routing assumes that networks will have lack of connectivity, with partitions between nodes. Vahdat and Becker's paper 'Epidemic Routing for Partially-Connected Ad Hoc Networks' [10] introduces a replication based, delay tolerant routing protocol where messages are passed onto nodes that do not have a copy of the message. Vahdat and Becker's paper is the key paper used to implement routing within this project. The term 'anti-entropy', as used in my dissertation, comes from this paper. An anti-entropy session occurs when two nodes come into communication range and exchange messages.

1.3.3 Safety in Rowing

ROWCUS [11], a company based in Switzerland, has attempted to solve this problem with a different technical solution – using radar rather than GPS to detect proximity to obstacles, and without networking. While ROWCUS has similar goals to my project, the technical methodologies are different. The main differences are use of GPS and networking – my project connects nodes together while ROWCUS has individual nodes. Additionally, ROWCUS has “decided not to pursue the commercial deployment of ROWCUS”, from a statement on their website [11].

Preparation

2.1 Starting Point

I had no previous hands-on experience with microcontrollers, although I had worked with Raspberry Pi single board computers. I therefore dedicated a small amount of time over the summer to learning about microprocessors and MicroPython, completing basic tasks such as flashing an onboard LED. While this was useful, my project is implemented in CircuitPython, so it would have been more beneficial to have explored this.

My project implemented a modified version of the Epidemic routing protocol. I had some experience with networking and routing protocols prior to starting this project. This was composed of the Part IB networking module and two weeks' work during an internship on a MANET with different routing protocol, much further abstracted than this project. Throughout the course of my project I took the Part II principles of communications course, further expanding my knowledge.

2.2 Choice of Hardware

Hardware was ordered before the start of term, in order to satisfy the requirements of the project proposal. The main factors in my hardware choices were size, weight, and cost. Items needed to be relatively small to allow them to fit on a rowing boat. If the components were overly costly, it may prohibit other rowing clubs from producing their own networks.

I chose to use a microcontroller to control the system due to the reduction in size and weight it would offer over a single board computer. The Raspberry Pi Pico was chosen due to large peripheral set, with support for both UART, SPI, and I2C protocols. This allowed for greater flexibility throughout the project.

The AdaFruit boards were chosen due to the strong community surrounding the hardware, with the AdaFruit boards being supported by open source libraries that allow rudimentary operations to be performed.

The AdaFruit RFM69 radio has a large community surrounding it. The chip has an SPI interface and 500m range, appropriate for the use case as rowing boats will take around 2 minutes to cover 500m. Additionally, I chose to use the 433 MHz industrial, scientific, and medical (ISM) band as it is free to use without licencing, allowing me and other rowing clubs to use it without additional bureaucracy.

The CD-PA1616S GPS has benefits similar to the RFM69, with community support and libraries for basic communication. It was additionally chosen as it includes a patch antenna and relatively short cold start time – these were important for the use case, as a delay in the collision avoidance device starting up reduces the overall utility of the system.

2.3 Requirements

The three requirements I identified as my success criteria were:

The Epidemic routing protocol is implemented within the network	Achieved
A user interface has been implemented to allow utility of the network	Achieved
An evaluation of the network has been carried out	Achieved

All of these requirements have been implemented during this project.

I also laid out several extension tasks. Some of them were drawn from my research into networking protocols other than Epidemic. For instance, I wanted to use a metric for transmission quality – received strength signal indicator (RSSI) in radio communication – to influence whether an anti-entropy session was initiated. Additionally, the GPS location could be used, either by only contacting nearby nodes to increase the probability that an anti-entropy session is successful, or prioritising sending messages about new obstacles to nodes that are near these obstacles. While time constraints have not allowed me to implement these extensions, I have implemented an extension allowing messages to have two priorities – normal and urgent.

These requirements were based around the use case for the project – as devices attached to rowing boats, where the nodes have high mobility. This mobility requires a high degree of flexibility within the network. I analysed the potential topology of networks. This was done by looking at example distributions of rowing boats on lakes and rivers. One potential use case for this network that I am familiar with is the river Thames. I analysed Google Maps and Earth's satellite view of the Thames along a 5.5km stretch of the Championship Course, pinpointing rowing boats and coaching launches, then adding them to a map with potential connections between nodes, assuming the radios have a range of 500m, alongside obstacles. Figure 2.3 shows a satellite image of a single sculler, a potential node in this network. Figure 2.4 shows the marked up map of the Thames, and figure 2.5 presents the abstracted network topology of these rowing boats.

Figure 2.3: A rowing boat seen on Google Earth [12]



Figure 2.4: Rowing boats, potential obstacles and assumed connections marked on a Google Maps map of the river Thames

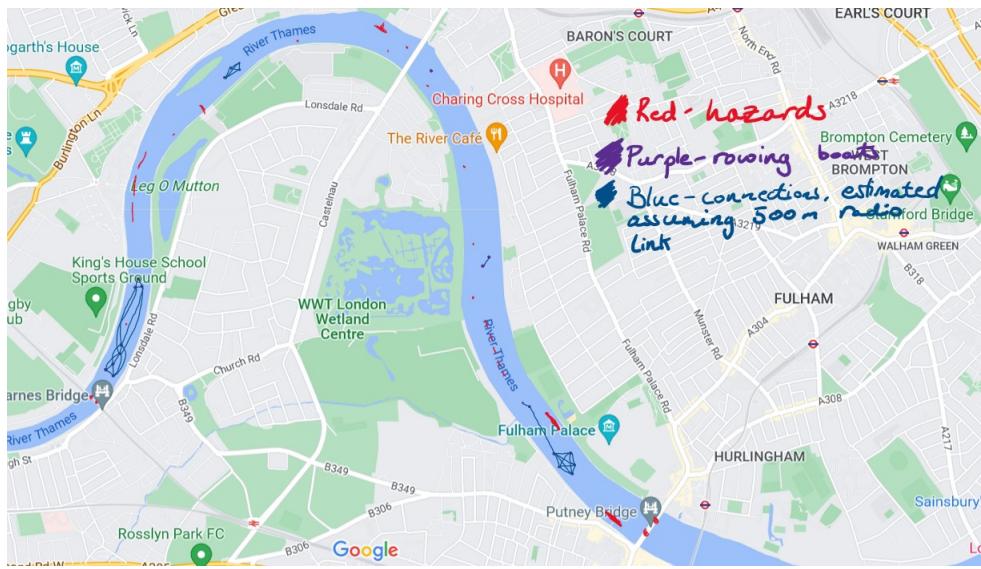
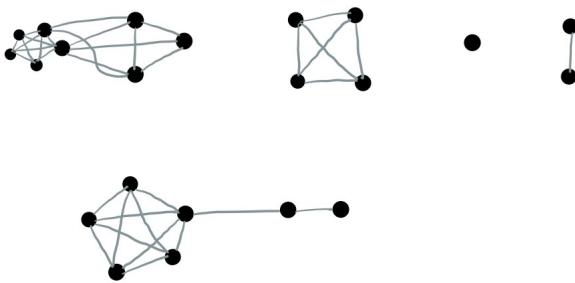


Figure 2.5: The network of rowing boats in an abstracted form



2.4 Choice of Programming Language

This project used CircuitPython, a branch of MicroPython, a version of Python for microcontrollers. CircuitPython was used as it can easily be run on the Raspberry Pi Pico, with no need to configure new development environments. Additionally, it allowed me to use Pylint to statically analyse code. This was particularly useful as the code was run on an external Raspberry Pi Pico, so running the code to find small errors would have been an inconvenience. Additionally, the existing AdaFruit libraries I used in the project were written in CircuitPython, so keeping the whole project to the same language reduced complexity.

GitHub was used to perform version control on the code and dissertation for this project. This also allowed me to fork repositories and submit a pull request to AdaFruit.

I used Visual Studio Code as my main Integrated Development Environment as I have used it on previous project, and it offered support for CircuitPython.

2.5 Summary of Research

2.5.1 MANET

A mobile ad hoc network (MANET) is characterised by wireless nodes, a frequently changing network topology and no reliance on pre-existing infrastructure. They are decentralised and therefore have no single point of failure [13]. This project constructs a MANET due to the lack of pre-existing infrastructure and the difficulties associated with setting up and maintaining a base station or similar. Requiring an infrastructure like this would also raise the barrier for entry for many clubs with limited funds and technical skills. Additionally, rowing boats can move between stretches of water, further supporting use of a MANET for this project.

2.5.2 Routing

Routing protocols find a path from a source to one or more destinations destination within the network. Different routing protocols optimise different parameters, and are better suited for different network topologies and applications [14]. Within MANETs, a routing protocol must allow the network topology to change over time. They tend to contain node discovery techniques to allow for this.

Before deciding on Epidemic as the routing protocol to implement for my project, I considered several other protocols. The the Better Approach to Ad Hoc Mobile Networking (BATMAN) protocol [15] is designed to route messages through MANETs, broadcasting originator messages (OGM) for node discovery. BATMAN has the interesting addition of a transmit quality (TQ) metric in the OGM packets, allowing the quality of connections between nodes to be factored into the route packets take through the network. While BATMAN does allow messages to be broadcast to all nodes, its primary focus is routing messages from one node to another. Additionally, while it allows for message mobility, it is not delay-tolerant.

Greedy Perimeter Stateless Routing (GPSR) [16] is a location based routing protocol. GPSR exploits the relation between geographic position and connectivity in a wireless network, where each node tells its immediate neighbours its current location. Greedy forwarding is predominantly used to send packets to nodes that are progressively closer to the destination, until the destination coordinates can be reached. Where greedy forwarding fails, GPSR uses perimeter forwarding (forwarding the packets around the perimeter of the region) until greedy forwarding can be used again. This protocol was ultimately deemed to be unsuitable for my project as, similar to BATMAN, its primary focus is in sending messages between two nodes. Additionally, the high mobility of the nodes in the use case means that forwarding packets to a set of coordinates does not mean the message will reach the intended destination, as the node may have moved.

2.5.3 Epidemic

I chose to implement Epidemic in my project [10]. Epidemic routing gains its names from its similarity to the spreading of infections. Each node replicates and transmits messages to neighbours that have not recently been contacted. These neighbours are discovered when each node broadcasts its existence to its neighbours. Epidemic was implemented in this project because it is a delay-tolerant routing protocol and best fits the likely network topology generated by rowing boats, as detailed in the Requirements section below. The networks generated by rowing boats have a high chance of partition, but the nodes are highly mobile. As Epidemic allows any node to carry network information it is best suited to the network. Additionally, Epidemic supports a broadcast functionality, sending messages to every node in the network, which is necessary for the use case as every boat should hear about potential obstacles.

Anti-entropy – message exchange – within Epidemic is initiated by the node with the lower ID. These lower ID node initiates anti-entropy by sending a summary vector a , representative of the messages

they have to another node. This node calculates logical AND between this summary vector and the negation of its own summary vector to produce the messages it has not seen that the other node has. It requests these messages. The node with the higher ID then sends its updated summary vector to the other node, and the node with the lower ID requests any messages it has not seen before. After a successful message exchange, the node is added to a list of recently contacted nodes, preventing anti-entropy from being conducted many times between two sets of nodes. This list is periodically cleared.

2.5.4 Media Access Control

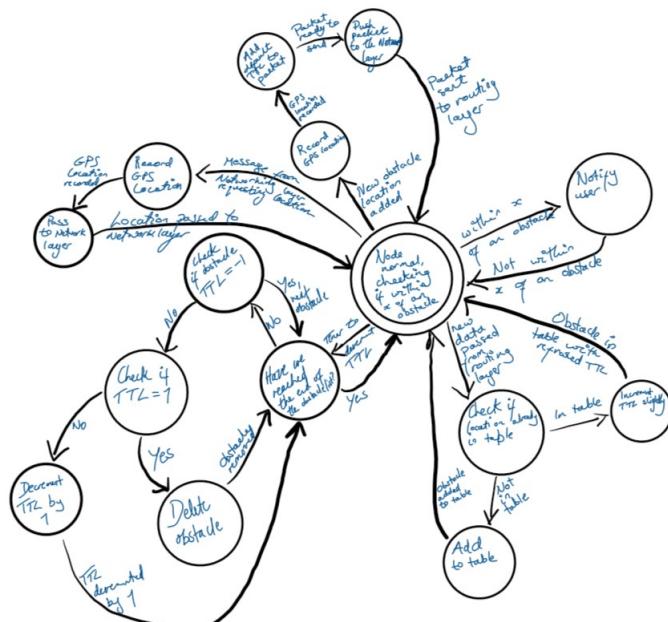
While these routing protocols often have mechanisms to minimise the probability of collisions, such as adding a jitter in the sending of discovery messages, none of them contain medium access control. Due to the probability of collisions between messages causing disruption to the sending of messages, particularly as all nodes are broadcasting on the same radio frequency (433 MHz). It was therefore prudent to include media access control in the system. Multiple Access with Collision Avoidance for Wireless (MACAW) is often used by ad hoc networks. MACAW uses request to send (RTS) and clear to send (CTS) messages to minimise the probability of collision. As discussed in the System Design section, MACAW inspired the medium access control in my project.

2.6 System Design

Having decided on the Epidemic routing protocol, I planned the structure of the software that would run on each node. I knew that the Raspberry Pi Pico uses the RP2040 chip, containing two cores. To make best use of the hardware, I decided to design application and networking threads that would run on each core, with global data structures and concurrency control to pass messages between the two layers and allow both of them to access the GPS board.

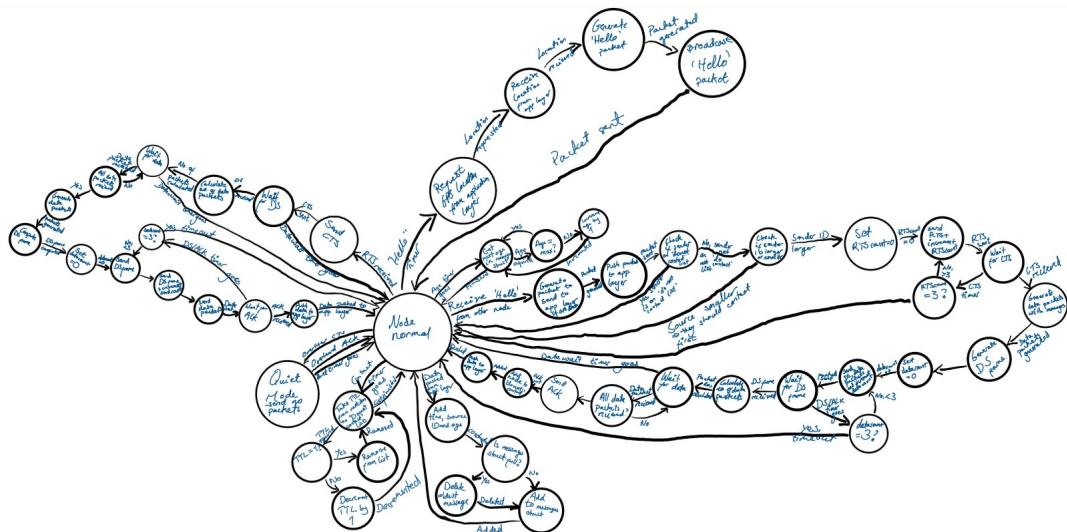
The application thread is responsible for notifying the user when they are too close to an obstacle. It also takes input from the user, generating new obstacles when a button is pressed. The initial state machine is shown in Figure 2.4. The a time to live (TTL) for each obstacle. If the object is permanent, such as a bridge, the TTL is set to -1 , indicating that it should never be removed.

Figure 2.6: The initial state machine for the application thread



The networking thread contains the implementation of Epidemic with media access control. While routing and medium access control are typically handled separately – in the OSI model they are in the second and third layers respectively – they were considered together for my project to prevent work being repeated and use the limited computing resources available most effectively. This means that the implementation of Epidemic will also change. Not only will the node refuse to send any messages after hearing a CTS for a set period of time, or until it hears an ACK, I also integrated the message vector exchange at the start of an anti-entropy session into the CTS and RTS messages. This minimised the number of packets sent over the network, reducing the overall probability of collisions or errors in transmission. This state machine has changed slightly since it was first designed.

Figure 2.7: The initial state machine for the networking thread



While these state machines were broadly implemented, the overall structure of the software changed, with only one thread running due to the limitations of CircuitPython and difficulties transitioning into MicroPython.

Implementation

Should definately make a new state machine / UML diagram to show how the code now works

Evaluation

Evaluation was done (mostly) according to the plan in appendix. It was split into evaluation of the MANET and the whole system.

4.1 Evaluating the MANET

Break this down into smaller sections – heavily quantify your results

4.2 Evaluating the System

We can def call this something better than the system? Idk the whole project, a more holistic evaluation? Emphasise that while the use case is kinda huge and untestable you tested within these restrictions and these parameters were met

Oh my, what happens to the GPS under a bridge? This could be a large and crucial flaw in your work...

I think the running of the system on the water is firstly to show that it does work in the use environment. I indeed would hope to set it up in such a way that the message is carried through multiple boats and a boat is notified of the obstacle before it reaches it. There is huge network topology variability here though, so through testing in the use case is not really feasible.

If it's difficult to test directly, perhaps what's needed is a time delay. That is:

Stationary node at side of river Boat goes out, finds obstacle, communicates that to the stationary node different boat goes out later, gets told about it from the stationary node. Test if it gets warned in the right place. Repeat with more boats/obstacles

Of course, the "different boat" could be the same scull with different hardware on it

I'd add the fifth node – you won't have accurate timing on that node, but you'll still be able to log time on the other nodes. That's fine if you use the new (timeless) node as an intermediate node, I think?

Conclusion

What did this project do? The project met and exceeded the success criteria.

5.1 Achievements

What have you done? In this project I have
The evaluation shows that. This project is weak in.

5.2 Learning

Aka lessons learnt / what I would do differently last time Probably spent too much time researching BATMAN when it didn't really fit the parameters Hardware is hard Just a stupid amount about radios and microprocessors

5.3 Future Work

I laid out several extension tasks. Some of them were drawn from my research into networking protocols other than Epidemic. For instance, I wanted to use a metric for transmission quality – received strength signal indicator (RSSI) in radio communication – to influence whether an anti-entropy session was initiated. Additionally, the GPS location could be used, either by only contacting nearby nodes to increase the probability that an anti-entropy session is successful, or prioritising sending messages about new obstacles to nodes that are near these obstacles. Encryption The success of my project will be defined by completion of the core criteria listed above. If there is time, I have set further challenges: 1. Case studies on the path and timing of individual packets are performed 2. The network is further evaluated by examining the power consumption of individual nodes as a proxy metric for traffic passing through a node 3. The User Interface of the device is evaluated 4. The application layer is further enhanced, using heuristics and extra data such as angle of attack from GPS and combining sensor data 5. The routing layer is further enhanced by passing additional data, such as location awareness, to the routing protocol Okay so we never shut anything down in a safe-ish way – just kinda pull the plug and fuck off... ? Actually you should definitely implement an editing of the Config file so we DO BETTER

Bibliography

- [1] S. Ramskill. (2023) Tweet by @lliksmar. [Online]. Available: https://twitter.com/lliksmar/status/1637147870682906624?ctx=HHwWgIC8zY_UqLgtAAAA
- [2] M. Taylor, "Equipment on the cambridge women's boat," 2013.
- [3] R. Pi, *RP2040 Datasheet A microcontroller by Raspberry Pi*, 2022.
- [4] J. Jubin and J. Tornow, "The darpa packet radio network protocols," 1987.
- [5] D. Beyer, "Accomplishments of the darpa suran program," 1990.
- [6] P. Nucholas and K. Hoffman, "Computational challenges of dynamic channel assignment for military manet," 2015.
- [7] R. Davidescu and N. Eugen, "Ad hoc networks for the autonomous car," 2017.
- [8] Y. Jin, X. Tan, W. Feng, J. Lv, A. Tuerxun, and K. Wang, "Manet for disaster relief based on ndn," 2018.
- [9] A. Moore, "Computer networking slide set for ib computer science," 2022.
- [10] A. Vahdat and D. Becker, "Epidemic routing for partially-connected ad hoc networks," 2000.
- [11] ROWCUS. (2022) Rowcus | rearview radar for collision avoidance. [Online]. Available: <https://www.rowcus.com/>
- [12]
- [13]
- [14]
- [15]
- [16]

Appendices

A – Guide to Building a Node

B – Evaluation Plan

Part II Project - Plan for Evaluation

March 2023

Overview

The evaluation for the mobile ad-hoc network (MANET) will be split into two parts – first the evaluation for the pure MANET and a whole system evaluation. The evaluation of the MANET will examine the implementation of Epidemic, the delay tolerant networking protocol will be checked for correctness and performance. The system evaluation will look at the MANET in the context of the use case, on the water.

All data will be logged on the node in a CSV file with columns

Node Address, Time, Time Since Node Startup, Event Type, Event Information where the Event Information varies with the event being logged and may contain the GPS location and message keys. This data will then be analysed on my device using Python code.

Evaluating the MANET

These tests be conducted in a field, as this will give an outdoor environment similar to the use case, but I will be able to better control the conditions the node is in. They will use four nodes, as this is the maximum number of nodes we can accurately calculate time for. Two nodes will use GPS to find the current time and two will use the serial connection to laptops to calculate the time. These tests will be conducted first on a small scale, with short tests using a small number of nodes, to ensure the tests can be run. After this has been confirmed, the tests will be run for a longer time with the maximum number of nodes.

The tests can then be compared to the evaluation in the initial epidemic paper [3], which simulated the nodes with 50 mobile nodes in a 1500 x 300 m space using the Monarch extensions to the ns-2 packet-level simulator rather than hardware as I am doing. Evaluation metrics examined included message delivery latency, delivery rate, the average and maximum number of hops a message took to get to a node.

The first test will be the percentage of packets delivered in the four node network. This will be time limited (i.e. if a message is not received in x minutes, it is considered undelivered). Nodes will randomly generate a new message every second, for a total of 25 messages, mirroring the structure of testing used in Vahdat and Becker's paper [3]. The nodes will be in a box of area $20m^2$ with the range of the radios reduced to approximately $5m$ to simulate the environment in which the system will be used. The nodes will move constantly.

Next, the transfer delay will be measured. This will be the average time taken for each message to be delivered, and will use the same setup as percentage of packets delivered testing.

Finally, the time taken to propagate messages after partition will be measured. This will include one-sided, asymmetric partitions, where only one set of nodes has messages the other set has not seen. It will also include symmetric partitions, where both sets of nodes have messages the other set has not seen. The number of unseen messages will be increased and each test will be run five times.

Figure 1: The setup and axes for delivery rate and transfer delay

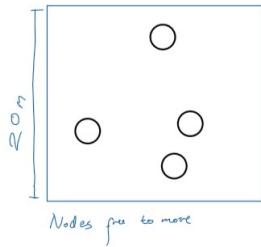
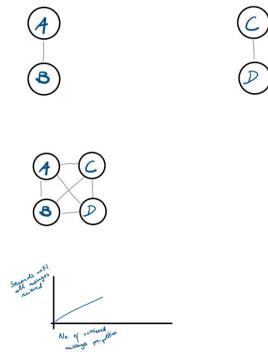


Figure 2: The setup and axes for partition testing



Evaluating the System

This will be performed on the water, the environment the MANET will be used in, after a ‘dry run’ on land to ensure there are no obvious flaws with the system. To examine the use of the system and how long it takes messages to arrive at other nodes, a well known obstacle has been selected. This is the red buoy at 51.48236626931181, -0.22641424521527762, shown below [1]. Using the time given from the GPS chips, we can then map the locations and time since the obstacle was added that other nodes receive messages about the buoy. This experiment will be run multiple times to gather a sufficient volume of data about the propagation of new obstacles.

Additionally, this will allow me to look at the behaviour of users when adding a new obstacle then tweak the MANET to fit. While there is a ground truth about the location of an obstacle, it is likely that most users will not be directly above the obstacle when they log it.

Figure 3: The location of the ‘red buoy’ obstacle [1]

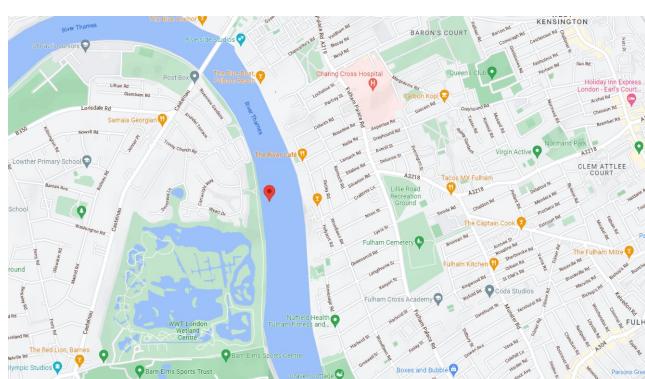


Figure 4: An image of the ‘red buoy’ obstacle [2]

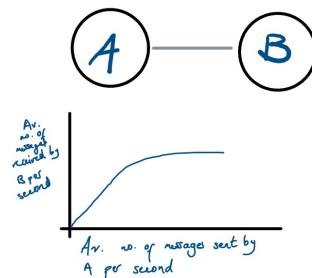


Extensions

If there is sufficient time, further evaluation can be performed on the MANET. This will be structured in a similar way to the tests in the ‘Evaluating the MANET’. Bandwidth will be tested in a fully connected network, where the number of messages per second transferred between two nodes may be found by generating random packets at set intervals at one node (node A shown below), and seeing how many are passed to another node (node B below). This test could then be performed with both nodes generating and receiving messages, to examine bandwidth on a two way connection.

Further extensions to the system evaluation will include a questionnaire for those who use the

Figure 5: The setup and expected graph for testing bandwidth



device, covering a range of users, including both coxes in coxed boats and rowers in coxless boats.

References

- [1] Google Maps. 51.4823, -0.2264. [Online] Available at: <https://www.google.co.uk/maps/place/51%C2%B0028'56.5%22N+0%C2%B0013'35.1%22W/@51.4820341,-0.2295313,15.5z/data=!4m4!3m3!8m2!3d51.4823663!4d-0.2264142!5m1!1e4> [Accessed March 2023]
- [2] Riddell-Webster, A. Red buoy. Taken March 2023.
- [3] Vahdat, A, Becker, D. Epidemic Routing for Partially-Connected Ad Hoc Networks. Published 2000. Duke University.

C – Progress Report

Part II Project - Progress Report

April 11, 2023

Name: Alex Riddell-Webster

College: Murray Edwards

Email Address: ahr38@cam.ac.uk

Director of Studies: Luana Bulat

Supervisor: Matthew Ireland

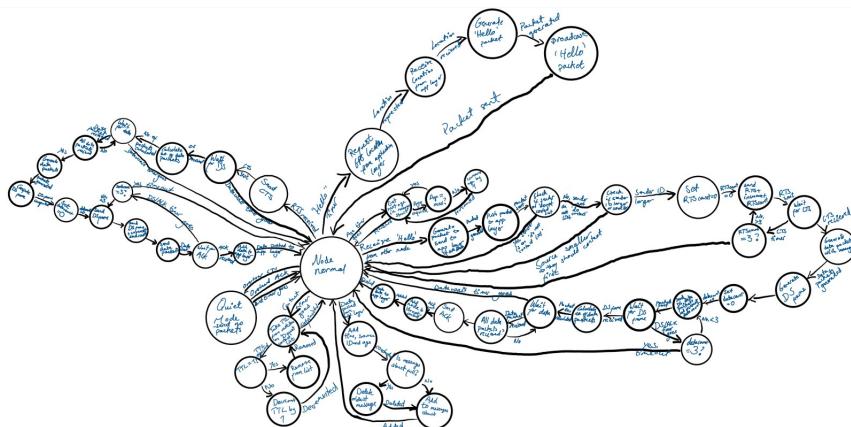
UTO: Professor Jon Crowcroft

Overseers: Ferenc Huszar and Andreas Vlachos

Title: A MANET to Facilitate Collision Avoidance in Rowing Boats

My project, a mobile ad-hoc network (MANET) to facilitate collision avoidance in rowing boats, attempts to reduce the frequency of rowing boat collisions. The technical core of the project is the Epidemic routing protocol [1], modified to include medium access control based on the Multiple Access with Collision Avoidance for Wireless (MACAW) protocol [2]. Both medium access control and Epidemic are implemented in the by the same state machine, to simplify the implementation and prevent work being repeated – a waste of the limited resources on the Raspberry Pi Pico [3]. The initial state machine is shown in Figure 1, although it has been changed during implementation. Most notably, data send (DS) packets have been removed and the information being put into the data packets to reduce the number of packets sent.

Figure 1: Network state machine

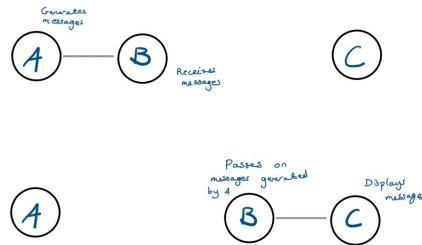


Construction of the MANET is going well. It has been constructed in hardware, working with the Raspberry Pi Pico, an ARM-based microcontroller without an operating system [3] and RFM69 radio. I have finished the networking machine so am currently tweaking and evaluating the network state machine while finishing the application machine. As the network has a physical implementation, I intend to test the network on rowing boats, the environment it would be used.

To ensure the network was delay tolerant, I ran a test with three nodes, A , B and C . At the start, nodes A and B were in range of each other and node C was out of range. I set node A up to generate random messages every 40 seconds, with a time to live (TTL) greater than 2 so the messages would survive for two ‘hops’ across the network. I then moved node B out of range of

node *A* and into range of node *C*, which then displayed any messages it received so I could check that they were the same as those generated by *A*, with a reduced TTL. Figure 2 shows the setup.

Figure 2: Using three nodes to check the network is delay tolerant



Another test involved four connected nodes, *A*, *B*, *C*, and *D*, where the transmit power of each node was significantly reduced, so each node had at most two connections. Node *A* generated messages, and I checked to see if *D* received them. I will use a similar set up in the future to test the percentage delivery and latency of packets. The setup is shown in Figure 3.

Figure 3: Using four nodes to check the network can transfer packets over several links



The most significant obstacles have been in radio communication. The FIFO buffer on the RFM69 was occasionally being overwritten as the controlling library was not clearing the FIFO. I modified the library to clear the buffer and allow the sending of fixed length packets. Changing to fixed length packets (64 bytes, the maximum length of the FIFO) allowed for more reliable communication. Additionally, CircuitPython (the language in which AdaFruit's libraries are written) does not support interrupts. To work around this, I poll to see if a condition is met when a corresponding timer elapses.

Given the work completed so far, I am two weeks behind the timetable laid out in October. As I am working on the application machine and evaluation of the network in parallel, the project will likely be back on timetable by mid-February.

The remaining work is first to finish the application machine and evaluate the MANET. Evaluation metrics will include the percentage of received packets, transfer delay and variance, and the time taken to propagate messages in a previously segmented network. Finally, I will pull the application and network machines together, running them on the two cores in the Pico, with concurrency control over key data structures and the GPS chip. A concern here is the Adafruit Blinka libraries allowing interoperability between CircuitPython and MicroPython [4], given the errors and incompleteness found in other libraries.

References

- [1] Epidemic Routing for Partially-Connected Ad Hoc Networks. Vahdat, A, Becker, D. Duke University. 2000.
- [2] MACAW: A Media Access Protocol for Wireless LAN's. Bharghavan, V, Demers, A, Shenker, S, Zhang, L. ACM SIGCOMM Conference. 1994.

[3] RP2040 Datasheet A microcontroller by Raspberry Pi. Raspberry Pi Ltd. 2022.

[4] GitHub - adafruit/Adafruit_Blinka: Add CircuitPython hardware API and libraries to MicroPython & CPython devices. https://github.com/adafruit/Adafruit_Blinka. Adafruit Industries. GitHub. Accessed January 2023.

D – Project Proposal

Part II Project – Project Proposal

October 14, 2022

Preliminary Information

Name: Alex Riddell-Webster

College: Murray Edwards

Email Address: ahr38@cam.ac.uk

Director of Studies: Luana Bulat

Supervisor: Matthew Ireland

UTO: Professor Jon Crowcroft

Overseers: Ferenc Huszar and Andreas Vlachos

Title: A MANET to Facilitate Collision Avoidance in Rowing Boats

Introduction

My project will implement routing in a Mobile Ad-Hoc Network (MANET).

Routing protocols find a path from a source to one or more destinations destination within the network. Different routing protocols optimise different parameters, and are better suited for different network topologies and applications [1].

A MANET is characterised by wireless nodes, a frequently changing network topology and no reliance on pre-existing infrastructure. They are decentralised and therefore have no single point of failure [2]. MANETs have a large range of uses, from the military [3] to facilitate communication, to autonomous vehicles [4] or disaster relief scenarios [5] to gather and move data across locations where previously existing infrastructure has been destroyed.

My project wishes to use a MANET to share a set of locations throughout a set of rowing boats, in order to facilitate collision avoidance. Collisions in rowing can cause damage to both rowers and their equipment. This project's motivation is to avoid rowing boats colliding with each other and with other obstacles. A radar and AI based obstacle detection system exists [6]. However, to the best of my knowledge, collision avoidance has not been attempted by networking boats together. My project will represent each boat as a node in a network. Each node will store a set of locations the user should be warned about; passing location data throughout the network will be the technical core of the project.

My project will be implemented in hardware, in the real world. In general, networking protocols can be implemented in simulation or in hardware. Depending on the nature of the simulation environment, it might not be possible to use exactly the same code in the simulator as in the real hardware. Due to the time constraints on a Part II Project, I intend to implement my project only in hardware.

As stated in the cover sheet, Human Participants will be used to help test and evaluate the project. This will comprise a few volunteers to row boats, allowing the network to be run on the water. These volunteers will all be members of Cambridge University Boat Club, able to safely row a boat and navigate the river where the network is being tested.

Structure

The first part of the project will be dedicated to research, looking at the Epidemic routing protocol. Epidemic was chosen as it is a delay tolerant routing protocol, and best fits the likely topology of networks generated by rowing boats. There is a high chance of partitions in these networks. However, the nodes in the networks will be highly mobile, meaning that data can still be transferred through the network through exploiting this mobility. A potential topology for the network, generated from looking at satellite images of a 5.5km stretch of the river Thames [7], is shown in Figures 1 and 2, both on a map and as an abstracted topology.

Figure 1: Rowing boats, potential obstacles and assumed connections marked on a Google Maps map of the river Thames

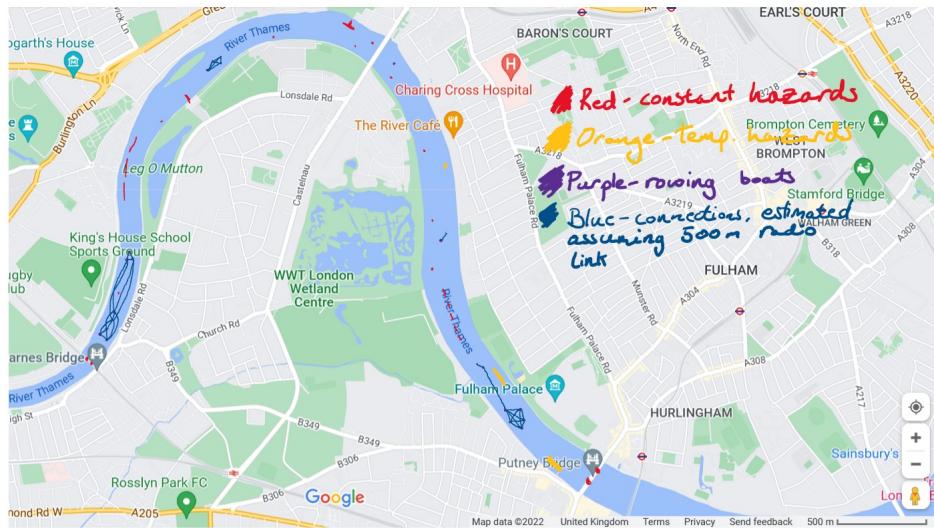
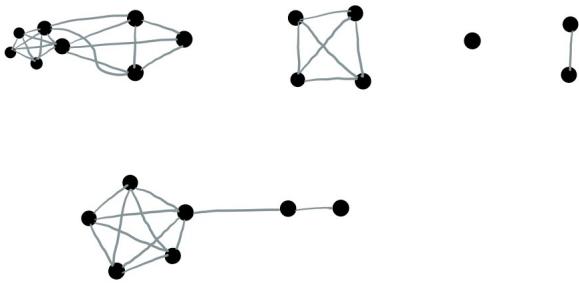


Figure 2: The network of rowing boats in an abstracted form



The first research phase will also decide on any changes that need to be made to the routing protocol to make it better suit the application. Finally, the first research phase will refine the evaluation metrics needed for the project.

The second research phase will look at microcontrollers, particularly the Raspberry Pi Pico. It will also consider multi-threading on the Pico and in CircuitPython and how this can be exploited to most effectively implement my Part II project.

After the research phases, I will implement point to point communication between two neighbouring (in radio connection range) nodes in hardware.

The next part of the project will implement broadcast and controlled flooding routing between

at least three nodes. A packet format will be defined as part of this, as flooding will form the start of the Epidemic routing protocol.

After a flooding protocol has been implemented, I will build on it to implement the Epidemic routing protocol. The code will be written in a two week block, then tested on hardware in a third week.

The application layer will then be implemented. This will ensure that the information passed through the network can be used. The application layer should warn the user when they are approaching an obstacle, and allow the user to add obstacles, which are then passed to the routing layer to be propagated through the network. My project aims to keep the routing and application layers separate for ease of construction, testing and evaluation.

The hardware will then be tested, tweaked and evaluated. Correctness will be evaluated first on land, likely in a field, where analysis of the network is easier and larger numbers of metrics can be examined than in the use environment. Performance will be evaluated in the use environment - on rowing boats on the water. I intend to evaluate the routing and application layers separately. Evaluation of the network will likely consider connected and partitioned instances of the network separately. Evaluation is likely to look at the time taken for the network state to be flooded through the nodes, and routing tables then updated, as well as a packet loss ratio [8]. Further evaluation would conduct some case studies, tracking a packet through the network and ensuring no unnecessary latency is added. The power consumption of each node could also be measured, giving a proxy measure for the traffic passing through each node. Due to time constraints, I consider these further evaluations to be extensions.

Success criteria

There are three success criteria I will hold for my project:

1. The Epidemic routing protocol is implemented on the network
2. An application layer to demonstrate the utility of the network has been implemented
3. An evaluation of the performance of the network has been carried out

Extensions

The success of my project will be defined by completion of the core criteria listed above. If there is time, I have set further challenges:

1. Case studies on the path and timing of individual packets are performed
2. The network is further evaluated by examining the power consumption of individual nodes as a proxy metric for traffic passing through a node
3. The User Interface of the device is evaluated
4. The application layer is further enhanced, using heuristics and extra data such as angle of attack from GPS and combining sensor data
5. The routing layer is further enhanced by passing additional data, such as location awareness, to the routing protocol

Plan of Work

Start of Block	End of Block	Block Length	Notes	Work to be Done	Milestones
14/10/2022	21/10/2022	7		Research - how to implement Epidemic protocol, evaluation methods used for ad-hoc networks	Develop a greater understanding of the Epidemic protocol and a plan for implementing it, create an evaluation plan
21/10/2022	28/10/2022	7		Learning how to use the microcontroller and boards	Ensure all the necessary hardware is available, develop a greater understanding of the Raspberry Pi Pico and CircuitPython
28/10/2022	04/11/2022	7		Start to work with the hardware - implement point to point communication between two nodes	Two nodes can send point to point messages
04/11/2022	18/11/2022	14	07/11 - Robotics Assignment 1	Implement controlled flood routing	Messages are flooded between at least three nodes
18/11/2022	02/12/2022	14	18/11 - 4s head; 28/11 - Robotics Assignment 2	Implement Epidemic routing protocol	Routing state information is shared between at least two nodes, Epidemic is implemented
02/12/2022	10/12/2022	8		Test, tweak and debug Epidemic implementation on hardware	Epidemic is implemented on hardware
10/12/2022	26/12/2022	16	14/11 - Trial 8s; Christmas	Time off	-
26/12/2022	02/01/2023	7	01/01 -> 11/01 - Camp	Implementing application layer - read location data from GPS and warn user when approaching known obstacle	The device warns the user when they are approaching a known obstacle
02/01/2023	16/01/2023	14	01/01 -> 11/01 - Camp	Implementing application layer - transfer data between the application and routing layers	The application layer is implemented on hardware
16/01/2023	23/01/2023	7		Tweaking the hardware, testing point to point links on land	The hardware runs on land, finish proof of concept
23/01/2023	30/01/2023	7		Water testing and tweaking	The hardware is implemented and run in the application environment (water)
30/01/2023	03/02/2023	4	03/02 - Cybercrime 1	Write progress report and presentation	Progress report and presentation
03/02/2023					
Progress report and presentation					
03/02/2023	14/02/2023	11		Evaluation and tweaking on land	The hardware is evaluated for correctness on land
14/02/2023	21/02/2023	7	17/02 - Cybercrime 2	Evaluation and tweaking on water	The hardware is evaluated for performance on water
21/02/2023	07/03/2023	14	03/03 - Cybercrime 3	Dissertation - plan and bullet point what will be said	Dissertation bullet point form (first draft)
07/03/2023	21/03/2023	14	17/03 - Cybercrime 4	Dissertation - write out preparation and implementation	Dissertation has implementation and preparation written out
21/03/2023	04/04/2023	14	26/03 - Boat Race	Time off	-
04/04/2023	18/04/2023	14		Dissertation - write introduction, conclusion, evaluation	Dissertation fully written, sent to supervisor to proofread (second draft)
18/04/2023	02/05/2023	14		Dissertation - Take on criticism, add references and appendices	Dissertation - final draft
02/05/2023	12/05/2023	10		Contingency	-
12/05/2023					
Final deadline					

Starting Point

I have a little experience with networking and routing protocols. My experience is limited to the Part IB networking module, although it is being expanded by the Part II Principles of Communications module and my research. I will need to add to my knowledge of networking and routing protocols.

I have previous experience using Raspberry Pi single-board computers with AdaFruit boards. I have no previous experience with microcontrollers. I will need to improve my knowledge of microcontrollers to complete this project, something I have set aside time for in my Plan of Work.

Resource Declaration

I plan to use my laptop to implement, evaluate and write up the project. It has a comprehensive system of backups through OneDrive and disk images. A backup of the project will exist with Git version control, hosted on GitHub. My own hardware, including Raspberry Pi Picos, breadboards and AdaFruit radio and GPS modules will be used to develop and implement the project.

Libraries to interface with the AdaFruit boards are written by AdaFruit in Circuit Python, and in my experience tend to be robust, although they occasionally contain bugs. If necessary, I can fork the code and implement bug fixes.

My project will partially rely on the correctness of routing protocols, work that others have already published. [9]

As the project has a real-world implementation, I have permission from Cambridge University Boat Club to test devices on their boats.

References

- [1] 2022 Part II Lecture Notes on Principles of Communications. Crowcroft, J. 2022.
- [2] Mobile Ad Hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations. Corson, S. and Macker, J. Network Working Group. 1999.
- [3] MILCOM'09: Proceedings of the 28th IEEE conference on Military Communications. Richardson, K, Jimenez, C, Stephens D. 2009.
- [4] AD HOC Networks for the Autonomous Car. Davidescu, R, Negrus, E. IOP Conference Series Materials Science and Engineering. 2017.
- [5] MANET for Disaster Relief based on NDN. Jin, Y, et all. IEEE. 2018.
- [6] DEVICE | rowcus. <https://www.rowcus.com/device>. ROWCUS. Retrieved 07/10/2022.
- [7] Hammersmith Bridge - Google Maps. <https://www.google.com/maps/place/Hammersmith+Bridge,+London/@51.4883478,-0.2302753,17z/data=!3m1!4b1!4m5!3m4!1s0x48760fb3f5c78f85:0x932267a238m2!3d51.4883478!4d-0.2302753>. Google. Retrieved 10/10/2022.
- [8] SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS AND NEXT-GENERATION NETWORKS Internet protocol aspects – Quality of service and network performance. International Telecommunication Union. 2011.
- [9] Epidemic Routing for Partially-Connected Ad Hoc Networks. Vahdat, A, Becker, D. Duke University. 2000.