SMARTS ENVIRONMENTS PROJECT

DOCUMENTATION

TEAM DEEZ NODES

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CHAPTER 0: INTRODUCTION

We are team “Deez Nodes”, consisting of eight students from various cultural and academic backgrounds. Each member contributes to the team with their own unique skill set and together we form an efficient team that strives to come up with creative and effective solutions for complex and urgent problems. For this project, our team is highly motivated to tackle the complicated problem of climate change.

The problem we are tackling for this project is slash-and-burn agriculture. With ongoing global warming, humanity is currently at risk of making the planet uninhabitable for many species. A major cause of global warming is the continuous increase of greenhouse gas emissions [38]. Over the past decade, deforestation and forest fires have contributed to approximately 10% of our annual carbon emissions. The primary reason for this is to make room for agriculture. In some cases, this type of deforestation is organized by the government, though it often is a result of the illegal actions of slash-and-burn agriculture [1][29].

The loss of forest not only negatively contributes to global warming, it also has destructive effects on biodiversity. It also disrupts the ability of forests to store CO2. Additionally, the rising temperature of our planet increases the risk of naturally caused wildfires, causing a destructive loop [38]. Therefore, deforestation by human intervention is a key contributor to climate change.

Mitigating this problem starts with wildfire detection, which is what this project will mainly focus on. Thus, our team proposes a node-based solution that is placed within specific forest sites to detect fires. The system allows for precise detection of forest fires and enables governments and other stakeholders to act rapidly and effectively. Each node contains sensors that can detect fires, a communicative device and a power supply. Together, the nodes form a network, in which each node communicates with its direct neighbors. Once one of the nodes detects something with their sensors it will pass the message along the node-network towards a central point where all the data will be received and checked. After this, the nodes can be tailored to the specific issue of slash and burn agriculture.

After evaluating a variety of solutions, including analyzing satellite imagery and wildlife tracking, the above mentioned solution was chosen as the most viable to detect and track wildfires. This report will showcase how we got to this solution and how we have implemented it.

CHAPTER 1: LITERATURE REVIEW

Effects of slash-and-burn agriculture and deforestation on climate change

Slash and burn agriculture is the method by which a part of a forest or similar ecosystem is burnt in order to create a more permanent place for agriculture. This has severe consequences for the environment and is usually way more destructive than shifting cultivation. In this method a forest is re-established after it has been removed for traditional agriculture. This often results in degraded grasslands or degraded fallows. Also, "the net CO2 balance in shifting cultivation is near zero if the forest returns to its original biomass and soil organic carbon status" (P.Bernard Tinker et al. 1996) Deforestation by contrast normally causes large losses of CO2 from the soil and vegetation. Greenhouse gas emissions are still difficult to quantify. Deforestation may lead to changes in evapotranspiration, runoff and local climate [1].

How and when higher climate change risk perception promotes less climate change inaction

This article explains how climate change awareness may result in a negative action taken by users. The article explains how there is little to no research in the field of how climate change awareness changes people's behaviour. The investigators conducted two experiments in order to demonstrate their hypothesis, which states that higher climate change awareness leads to positive action taking. "The results showed that, as expected, higher levels of climate change risk perception were related to less climate change inaction, and this relation was mediated by enhanced climate change belief and heightened environmental efficacy in a sequential manner. Furthermore, the effect of climate change belief and environmental awareness was stronger among those who had a higher level of mindfulness" [2].

Role of renewable energy technologies in climate change adaptation and mitigation: A brief review from Nepal

This paper makes a very interesting connection regarding the ability of a country to adapt into renewable energy technologies. It also explains how climate change mitigation can be achieved by the use of renewable energies. "Nepal has installed micro-hydro projects, solar power, improved cooking stoves, biogas technology, improved water mills and wind energy to mitigate and adapt to climate change." It also specifies further other developing options to mitigate climate change [3].

Growing Up: How Vertical Farming Works

Vertical farming might be the sustainable solution to a lot of problems regarding food production and demand. With vertical farming, factors like lighting, temperature, nutrients and soil can be controlled, to create optimized and enhanced conditions for production. As vertical farms require far less space, they can be installed in warehouses in or near populated areas. This reduces the distance between production area and distribution area, reducing CO2 emissions caused by transportation. Seasonal weather patterns that are inconsistent due to climate change are not an issue anymore as all the farming is done inside these controlled, indoor environments. No harmful pesticides are required to keep the plants safe from insects. The water management is also a lot more efficient. The amount of water needed is less, and a lot of the water is often recycled [4].

Status of electronic waste recycling techniques: a review.

This paper focuses on the importance of recycling electronic waste (e-waste) and the different techniques used for this purpose. E-waste such as printed circuit boards consists of various plastics, ceramics, metals, and precious metals. All of these components are valuable and, if left alone, can be harmful to the environment. The general recycling process consists of 3 phases: dismantling, upgrading and recycling. The dismantling process is very labor intensive and largely splits all of the components into their respective parts. The upgrading phase further separates the waste by using magnets and density. And the upgrading phase is used to completely separate all the metals and plastics from each other, as much as possible. This phase consists of various techniques such as using heat (pyrometallurgical) or dissolving and separating (hydrometallurgical) [5].

Global warming triggers coral reef bleaching tipping point

Coral reefs bleach at 1°C above the average temperature of the hottest month, and die if this temperature is exceeded by 2°C. Coral reef bleaching events are increasing in frequency. If there's not enough time between these high temperature bleaching events, the corals will not have enough time to recover. Coral diseases spread faster when it's hot. Coral reef ecosystems are most sensitive to increased temperatures, and thus will be the first to go extinct because of global warming. It can take 3-4 million years for coral reefs to evolve, so instant action is needed to prevent extinction [6].

What is coral reef bleaching, and why do coral reefs need to be saved?

Coral is actually not a plant, but an animal that has a symbiotic relationship with a type of algae, called Zooxanthellae. This algae makes 90% of the food the coral needs, along with giving it bright colors. If the water temperature is too high or low, which happens a lot more because of climate change, those algae will get stressed out, and leave the coral. This causes the coral to bleach, making it vulnerable to predators and diseases. Coral reefs are important as they provide food and shelter for other creatures. They're like the buildings in a city. Coral reef bleaching is a hazard for entire ocean ecosystems [7].

Most people waste more food than they think—here's how to fix it

The national geographic article 'Most people waste more food than they think — here's how to fix it' addresses the issue of food waste and how one third of all food is thrown away. The article points out issues of why it seems so hard for us collectively, to stop wasting food, naming issues like:

- Expiration dates giving a false sense of food having grown bad
- Overstocking while buying groceries leading to food growing bad before being eaten
- Social problems like taking food back home from a restaurant or event without planning to actually eat said food

Some ideas get mentioned on how to approach these issues, like generally having smaller plates so food doesn't get needlessly put on the plate, and having a smaller fridge to encourage smaller shopping, and how frozen food can help us minimize food waste, due to its long shelf life and ability to keep fresh food edible longer.[8]

Smart Water Management Platform: IoT-Based Precision Irrigation for Agriculture

"This paper introduced the SWAMP architecture, pilots and deployment scenarios for the four pilots using FIWARE as the underlying IoT platform." SWAMP (smart water management platform) is a project based on using smart technology and the IoT (internet of things) for more efficient irrigation. The problem this tries to solve is the overirrigation that often occurs during farming, this leads to lower crop yields and more water usage than necessary. The platform uses technology from FIWARE, an organization that provides open-source software for smart technology. The system first measures a variety of factors such as moisture, temperature and crop growth. This data is combined with external data such as weather forecasts and drone shots of the land to calculate the amount of water needed. This is then presented to the farmers who manage the irrigation. SWAMP has several pilots; these have been shown to reduce water and energy waste as well as be useful in determining crop quality [9].

Coastal Darkening Could Block Kelp's Carbon Sink Potential

Coastal darkening is a phenomenon wherein small particles, often fertilizer, waste, and plant matter float to the top of a body of water and block sunlight from reaching the plant life below. This has negative impacts on the growth of phytoplankton and kelp forest that need sufficient sunlight to grow and reproduce. The number of phytoplankton impacts the rest of the sea life, as it is an important part of the food chain and could decrease biodiversity. Less sunlight also means that kelp grows slower and therefore not only sequesters less co2 but also provides less food and shelter for marine life which again impacts biodiversity. This effect can be extremely prominent with a 95 percent reduction of productivity of kelp, which correlates to 4.7 times less carbon being sequestered. Coastal darkening is a subject with relatively few studies, which means that we can't be sure of the exact effects and impacts. However, kelp does remove a significant amount of carbon from the atmosphere and solutions for this problem could be implemented on a local level, instead of a global one [10].

(Micro)plastic crisis: Un-ignorable contribution to global greenhouse gas emissions and climate change

The global plastic production increases rapidly. With this growth, plastic industries have become the most important and rapidly growing source of industrial greenhouse gas emissions. By impacting species that form the basis of the marine food chain, plastic pollution plays a less direct, but important role in climate change. Current strategies and policies to solve the plastic crisis, such as recycling and reducing single used plastic, face many challenges. Nonetheless, the current plastic growth trajectory calls for much needed change in all aspects of the plastic life line. The global emissions from plastic in 2030 and 2050 are estimated to reach 1.34 and 2.80 gigatons per year, respectively. Therefore, change is needed through cooperation and coordination all over the world through policy formulation and technical innovation [11].

Microfiber pollution: an ongoing major environmental issue related to the sustainable development of textile and clothing industry

In the absence of microfiber degradation and effective recycling technologies, the amount of microfibers in the environment will drastically increase with the current growth in textile production. Textile factories play a big role in microfiber released in solid waste and wastewater. Though, the economical importance of the fashion industry in countries where these textile factories are mostly situated will often overshadow the environmental costs of textile production. Next to production lines, intervention of individual textile consumption can effectively reduce environmental pollution caused by landfill and burning. The current global approach to addressing microfiber pollution is largely lacking and is in need of technological innovations. Various interventions and innovations through collaboration at all levels of the fashion chain are needed to meet the sustainability needs of the textile and fashion industries [12].

Global terrestrial water storage and drought severity under climate change

The hydrological cycle, the sum of the processes involved in water movement from the land and ocean surface to the atmosphere and back, is modulated by the terrestrial water storage (TWS).

TWS is also a key determinant of water availability and an indicator of drought. This research paper shows that the TWS in many regions could be reduced by greenhouse gas forcing. It predicts that around the mid- and late twenty-first century the TWS is projected to decline substantially in the majority of the Southern Hemisphere. With a global increase of 17-34%, the population of all continents (except for Asia) will experience longer periods of moderate, severe, extreme, and exceptional drought. To prevent the increase of drought periods, current greenhouse gasses in the atmosphere have to be decreased drastically [13].

Importance of food-demand management for climate mitigation

Currently, the actions being taken to increase agricultural yield will not be enough to meet the expected food demand in 2050. Currently, it is expected that food demand will increase by 35-56% between 2010 and 2050 due to population growth, economic development, and urbanization. To avoid more tropical forests and savannas getting lost to agriculture, demand should decrease. In the scenario where food waste is reduced by 50%, cropland area goes down by 14%, greenhouse gas emissions (GHGs) reduced by 22-28%, and fertilizer and water demand will decrease. When also stimulating people to change their diet to a more healthy, plant-based one, cropland area will be decreased by a further 5% and GHGs by a further 45%. Yet, even in these scenarios, areas like south asia, water will still be an issue [14].

The circular economy of E-waste in the Netherlands Optimizing Material Recycling and Energy Recovery

Currently, e-waste collection and recycling in the Netherlands is organized by “Wecycle”, In 2016, 80% of the 110,000 tonnes of e-waste was recycled to useful materials and 17% was recovered as energy. E-waste recycling not only helps the climate, but also creates more jobs with better salaries compared to landfills and incineration. Sadly, recycled e-waste has the lowest demand coverage of any recycling categories. As the current economic growth is coupled with an increase in material consumption, it is of high importance to decouple them. Additionally, despite current efforts, 2015 saw a 30% increase in e-waste in landfills. Lastly, not all e-waste is recycled by the same standard. As a result, a lot of the recycled materials end up being of low quality. Moreover, many e-waste recycling plants are still found to contaminate the environment with toxic chemicals [15].

Climate change, tourism and outdoor recreation in Europe.

Climate change and tourism have a two way relationship. Whereas climate change has a negative impact on tourism, tourism also has a negative impact on climate change. Europe is currently the most popular destination for tourists and provides a variety of different weather climates. However, as the world heats up, tourists may change their timing, frequency, duration, location, or a combination of these factors. For example, the mediterranean area may get too hot during the summer, possibly causing tourists to go there during autumn or spring instead. Also many outdoor activities like festivals, concerts, sporting events, or just walking around in a city, may get too uncomfortable due to the increase in temperature. Due to warmer temperatures during winter, less snow will fall on the mountains, causing a significant decrease in ski areas. Currently, leisure activities use 3.2% of the global energy consumption and are accountable for 5.3% of all CO2 emissions. 94% of these contributions to global warming are due to transportation [16].

Life Cycle Assessments Of Food Systems

Life cycle assessment of food systems, is an approach of analyzing each different area in the food production chain, to determine how much climate impact a food product has in its entire 'life' span. Part of this cycle are the raw materials used for farming, manufacturing, distribution, retail, preparation, and finally the 'functional unit', which describes the finished meal.

Each step has its own climate impact, and with LCA one can analyze and determine possible mitigation opportunities to reduce the impact for each specific area [17].

Who Is Responsible For Climate Change?

The top three mass producers are China with 27%, USA with 15% and Europe with 10%. Combining all of our greenhouse gasses, we're emitting 51 billion tonnes of carbon dioxide equivalents each year. Even though we have all these facts and everyone acknowledges it, nobody is taking reasonable steps to improve or change the way things work right now and it is alarming [18].

Do we Need Nuclear Energy to Stop Climate Change

The benefits of nuclear energy and how much more efficient it is compared to fossil energy can not be denied. Nuclear energy has the potential to replace the old ways entirely, but has its own unique problems. With all the information provided it lets the viewer decide what to do and what's right for the planet and the safety for the future generations [19].

Loss of Arctic ice impacts everyone

Disappearing sea ice is a big problem caused by global warming. For example, Arctic sea ice is melting at a rate of almost 13% per decade, which negatively affects the whole Earth. The article mentions several consequences that have been noticed so far:

- Temperatures - the Arctic and Antarctic are covered in snow and ice which reflect heat back into space. As the ice is melting, less amount of heat is reflected which contributes to temperature increase worldwide.
- Coastal communities - ice melting causes a rise in average sea level which enhances the risk of coastal cities and small island nations to flood.

- Food - ice loss causes increased heat waves and unpredictability of weather which damages the crops.
- Wildlife - sea ice is a natural habitat for many animal species, so rapid melting of it can cause their extinction.
- Permafrost -as Arctic ice and permafrost melt, methane which is stored there and contributes to climate change, is released.
- Shipping - melting of the ice opens new shipping routes in the Arctic which can be very dangerous [20]

Climate change is threatening mental health

The report discusses the key role that climate change plays in individuals' psychological well-being. Since not many people are aware of the threats that climate change poses to mental health, it is an important aspect of climate change that should be discussed more. In the text, we can find arguments that prove the negative influences of environmental changes on people's mental health:

- People exposed to climate and weather related natural disasters can experience mental health problems like anxiety, depression or PTSD. The way that the media present climate change can also negatively influence somebody's mental well-being.
- People who struggle with mental illnesses are even more endangered by climate change; both physical and psychological problems can increase due to extreme heat. This phenomenon is explained by the prescribed psychoactive medicine that weakens the body's ability to control temperature. [21].

CHAPTER 2: IDENTIFICATION OF GENERAL PROBLEMS AND CHALLENGES

From the literature review, nine general problems and challenges have been identified:

1. Unregulated amount of CO2 created by slash-and-burn agriculture and deforestation.
2. Climate change causes coral reefs to bleach.
3. E-waste needs to be recycled more often and more effectively.
4. Poor water management leads to over irrigation.
5. Greenhouse gas emissions increase periods of drought of terrestrial water storage.
6. The growing plastic industry causes more (micro)plastic pollution.
7. Current agricultural yield increase will not meet the current food demand increase.
8. Food consumption is a huge system, with each step impacting climate in different ways.
9. Climate change negatively affects people's mental health and well-being.

CHAPTER 3: IDENTIFICATION OF RELEVANT PROBLEMS

Having identified nine general problems and challenges, further research has been conducted on five of them.

Agriculture

Up to 30% of all global greenhouse gas emissions are caused by the agricultural sector, this is due to a variety of factors: cattle and other livestock, both produce gas directly through the extraction of methane (either in the form of manure (nitrous oxide) or belches (methane)) and indirectly through the production of feed and transportation [22] [23]. When growing crops large parts of forests are burned down to create space for farmland, this releases the stored Co2. To prepare for droughts and in fear of under irrigation farmers often use more water than necessary and in doing so wastewater and lower crop yields. Fertilizer is rich in nitrogen to accelerate crop growth. However, during this process, nitrogen is released into the atmosphere where it becomes nitrous oxide, a potent greenhouse gas.

Problems:

- livestock produces large amounts of greenhouse gasses. (Is already being addressed)
- forests are burned down to accommodate more farmland. (This falls under deforestation)
- Over irrigation lowers crop yields and wastes water. (Is already being addressed)
- Fertilizer releases large amounts of nitrogen (and thus nitrous oxide).
-

The problem of how fertilizer and manure produce nitrous oxide hasn't yet been addressed properly and does have a large impact on greenhouse gas emissions. Therefore, it would be a problem we could address. Nitrous oxide contributes to about 6% of total emissions in the agriculture sector [24].

Recycling

With increasing production of materials such as plastics, textiles, and electronics, pollution and production have become important contributors to the increase of global gas emissions [5][11][12]. With their innate characteristics, many materials have the potential to be reused or recycled. On average, the recycling of solid waste could save around 40% of electricity, and could avoid large amounts of carbon dioxide and methane gas emissions [25]. Right now, the process of recycling materials is not yet addressed effectively in many countries. Also, recycling is no silver bullet when it comes to waste-less production and use of materials, as it still faces many challenges. Though, various levels of the recycling chain have the potential to be improved or invented, which could make a significant difference for pollution and production waste and (indirectly) the release of greenhouse gas emissions.

Mental health

Climate change not only affects the planet, but the individuals living on it. A relatively unknown problem are the threats that it poses to mental health. The increase of natural disasters caused by global warming exposes more people to such extremes which can result in mental health problems such as anxiety, depression, and the loss of personal identity and control. Mental well-being can also be influenced by the representations of climate change by the media [21]. The distress that people experience due to climate change and future developments can also influence important life decisions, such as whether to apply for university or to have children in the age of climate change [26]. The impact that climate change has on mental health is still largely unexplored. Nevertheless, it already affects us all and will increasingly play a role in our daily lives.

Food waste

Currently, about a third of the global food production is waste. Besides the ethical concerns, it also is an environmental one. Wasting food is also wasting water and energy, altogether, this relates to 6-8% of human GHG emissions. This problem seems really interesting, realistic, and relevant for the project. There are many ways in which society is trying to reduce food waste, but not to an effective enough extent [27].

Deforestation

Over the past 3 decades, 420 million hectares of forests have been lost due to deforestation and burning of forests. Especially the burning of forests especially leads to a huge release of carbon into the atmosphere, they contribute around 10% of our annual carbon emissions, part of this is an increase in forest fires which is a direct result of global warming, but the primary source for all these emissions is the direct result of humans burning forests in order to create land for agriculture. Partly those are government organized deforestation efforts, but primarily these actions are the cause of illegal slash-and-burn agriculture.

CHAPTER 4: PROBLEM SELECTION AND MOTIVATION

After discussing the relevant issues and general problems, the group has decided on the problem of slash and burn agriculture and deforestation which creates unregulated amounts of CO_2. The group believes mitigating this problem to have the most meaningful impact on the environment.

One hectare of trees can store up to 400 tons of carbon, which they collect over the spawn of their lifetime through photosynthesis. With this trees are one of the most important carbon sinks of our planet, helping to regulate and control carbon emissions into our atmosphere. When trees are burned “wood emits more CO_2 than fossil fuel per unit of energy released” [28].

Slash-and-burn agriculture relies on burning down huge hectares of forest to make room for agriculture, which uses the fertile soil of the forest to grow crops. In South American countries like Brazil and Argentina, countries that have huge stretches of the Amazon rainforest inside their country borders, the forest is systematically burned down in order to create space for agriculture and land, just between August 2020 and July 2021 13,235 square kilometers of forest was lost in Brazil due to human intervention [29].

Annually, 4.8 billion tons of carbon are released into the atmosphere every year due to burning of forests, which amounts to around 10% of annual global carbon emission. These carbon emissions contribute in significant amounts to global warming, which in turn leads to more forest fires, sour oceans, loss of biodiversity, and similar.

Crop-and-burn agriculture and logging happens in large parts illegally in remote zones with hard access and weak governmental control, and little to no means of keeping track of what is happening in those areas. For example in Mexico, estimated 70% percent of all logging is illegal [30]. Our goal is to create an approach of introducing a form of control to these zones, being able to notice early on when illegal logging or crop-and-burn agriculture is happening, in order to respond to it accordingly, with the goal of stopping or at the very least, diminishing the impact on the forest and climate change of these actions.

CHAPTER 5: POTENTIAL SOLUTIONS

After identifying the problem to mitigate, five different potential solutions for it have been identified. After identifying these potential solutions, each of them has been reviewed in terms of effectiveness and if they are realistic for this project.

Satellite imagery

The slash-and-burn culture removes large areas of wood. Therefore the view of the forest from above will drastically change. With satellite imagery and deep learning, areas where changes are identified that correspond with the image of a burnt down forest could be identified [31]. With this information, local authorities or stakeholders can respond relatively quickly to stop these illegal activities. A downside to this method is that a relatively large amount of forest has to change in order to be identified correctly [32]. This is time wasted when the burning occurs, and will not serve as a direct response to the problem. Other things to consider are the possibilities of this method within the scope of the project. For this solution, images would be used to evaluate the changes in the forest. However, the camera device that allows for these images, the satellite, would not be created with the project. So, in terms of working on a solution using satellite imagery, the focus of the project would mainly be on the classification of the images rather than working with sensors.

Node based forest monitoring

Using nodes, equipped with sensors, possible cases of wildfires and slash and burn agriculture could be identified. Different methods of detecting these would be for example CO2 sensors that detect if a certain threshold of CO2 in the air has been reached, disturbance sensors that detect alterations, fire sensors and temperature sensors. If a possible fire has been detected by a node, it will signal other nearby nodes in the direction of a central node connected to the network. A drone, equipped with a camera, is then sent to check if there really is a fire and action has to be taken. As a solution, this seems accurate and realistic enough for this project.

Camera equipped drones

Another way of detecting fires is by having camera-equipped drones automatically patrol an area and use AI to detect the fire. Fires could be detected using brightness, motion clues, and image processing using infrared camera input [33]. Additionally, by making use of thermal cameras, large hot areas can be detected as they show up as white blobs. By also using colored images, the hot area can be detected as fire [34]. This method has a lot of potential and the applications are currently being tested to detect wildfires [35]. While the idea is good, the scope of this project is too little to realize this idea. Additionally, of the current issues that experts in the field are having are about things like battery life and patrol route optimization [35]. These problems are deemed to leave too little room for novel ideas.

Wildlife tracking

Another way of detecting wildfire is by equipping the wildlife in the area with trackers. These animals would send out location data at certain intervals to be monitored for their movement and behavior to detect and predict possible fires. Specific types of animals that usually reside in one area need to be selected to be chipped, as those would be the most reliable source of information, since any unexpected movements could be linked to possible threats like forest fires. Environmental temperature could also be measured by chipped wildlife, to be able to detect sudden temperature spikes [36]. However, this solution is deemed as too inaccurate and inconvenient. Possible issues arise when thinking about battery life and equipping a large group of animals.

Soil composite testing

Soil composite testing can be used to identify the most fertile and therefore most suitable piece of land. This information can be used to identify the land that is most likely to be burned down for agriculture. When soil is used for long periods of farming, without rest, minerals that are vital for the plant's growth become more scarce, which leads to a decrease in crop yields. Using this information we could predict patches of land that will soon no longer be of use and will be replaced with new land, which is acquired through slash and burn . This could allow us to get a rough time frame of increased slash and burn in a given area. However, this method is speculatory and could be an invasion of privacy for the farmers who own the land, making it impractical as a solution. Additionally, in practice, this solution is too time consuming.

CHAPTER 6: SOLUTION SELECTION

Motivation

After looking at solutions mentioned in the previous chapter, we found that many of them come with major challenges.

Satellite imagery can provide information and data about a large area, to be able to detect large fires, but precise measurements and accuracy are a big enough issue to the point of unreliability of this potential solution.

Drones have a lot of potential and the applications are currently being tested to detect wildfires [34]. While the idea is good, the scope of this project is too small to realize this idea. Additionally, the current issues that experts in the field are having are about things like patrol route optimization, and battery life that greatly limits flight time [34]. These problems are deemed to leave too little room for novel ideas. Drones are also generally very expensive and often require gas to fly, which is not good for the environment.

Wildlife tracking would be difficult to measure. A very good understanding of wildlife movement is needed to identify possible fires based on movement. A very good understanding of wildlife movement would be needed to be able to identify if there's a fire or perhaps some other threat. Wildlife would need to be equipped with tracker chips, which is a difficulty on its own. Also, a large number of animals in a wide area would have to be tracked for accurate and reliable measurements.

Soil composite testing would need lots of cooperation with farmers in different areas. It would also be a very work- and time-intensive method to tackle slash-and-burn agriculture.

Considering the accuracy and scalability of the various solutions, we believe that using nodes to track wildfires is the most viable solution for us to work on. Additionally, whilst outside of the scope of the project, nodes can easily be adjusted to not only fit general wildfire detection, but also fires specifically caused by slash and burn agriculture.

CHAPTER 7: METHODOLOGY

Node Based Forest Monitoring

To create the nodes, different sensors need to be connected and cased. Temperature, smoke and fire sensors are connected to an Arduino, and utilized to detect possible fires. Wireless communication modules are then connected for the nodes to send out signals. A solar panel is installed alongside a battery, after which the entire system is encased. The nodes are built from relatively cheap sensors to ensure affordability and increase scalability.

Before the nodes can be used, sensor calibration is required to determine if the acquired sensors are appropriate to be used. Calibration ensures the most accurate measurements when it comes to detecting fires. The high variety of environments call for leaving appropriate margin for error. Potential issues include poor node placement, or an abundance of trees and plants that could interfere with communication and block out sunlight, which causes power to be deprived from the nodes.

Detecting fires

For fire detection, three different sensors are used. A DHT11 temperature and humidity sensor, an MQ-2 smoke detector and an IR sensor are present in each individual node. The DHT Arduino library is used for the temperature sensor. The remaining sensors return a value from which can be deduced if there is a possible fire. Fire is detected if the reading of DHT11 or MQ-2 crosses a certain threshold. The infrared sensor sends a digital signal if a fire is detected. Whenever any of the sensors are triggered, the communication module is activated and sends the message to the receiver.

Communication

For node communication with the NRF24L01 module, the libraries NRF24, NRF24.Network and NRF24.mesh are used. The mesh library allows the nodes to automatically form pathways between the master and receiver. If no direct connection is available, this will happen through other nodes. To reduce interference with wifi signals, the band frequency was set to a value close to 2.5GHz instead of the default 2.4.

The transmitter code initially confirms the node ID and forms a connection to the mesh. After this, the nodes send a message through the mesh to the receiver node every six hours, or whenever a fire is detected. This message is a specific case, a single character used to identify which message is being transmitted.

The receiver code uses this case to display the correct message, after which it presents the incoming variable with a data type message of the right type (int, float, string etc.). If the transmitter node is unable to form a connection to the network or send a message, it will continue trying to establish a connection until it succeeds and can resume sending data.

Building the casing and powering the system

In order to contain all the components necessary for the autonomous functioning of the nodes, an appropriate casing was built. Polylactic acid (PLA) was selected for the structural shell that encases the electronics. PLA is a suitable material for this project since it is inexpensive, easy to form and does not create fumes when shaped. The casing was given shape using additive manufacturing (3D printing), parting from a design modeled in a computer aided design software Autodesk Fusion 360.

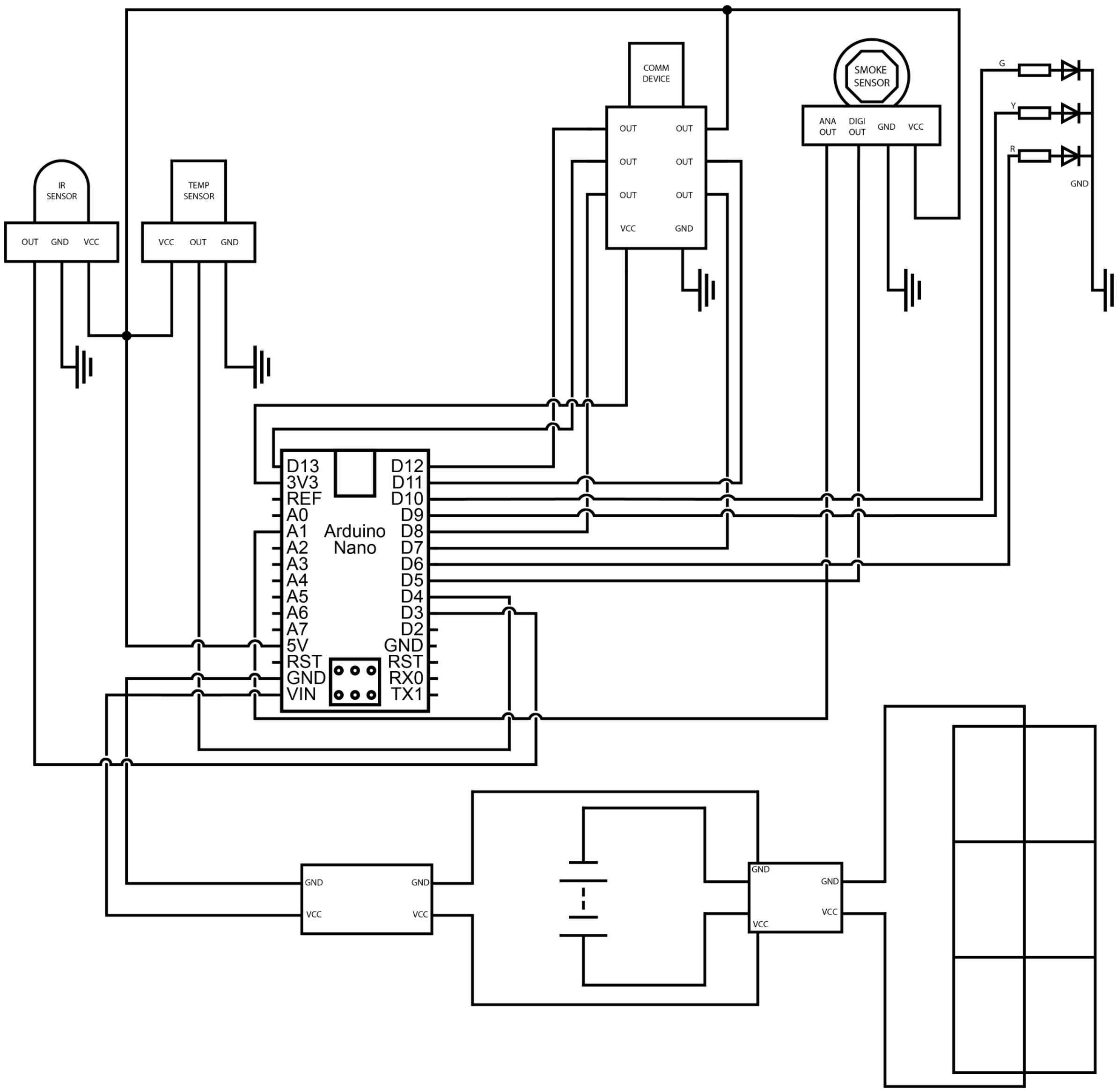
The node appearance was designed with functionality in mind. Its characteristical triangle shaped form gives it the unique ability to stand in different orientations. It can be laid on its side on flat surfaces, buried on the ground using its lower point, or strapped to a tree using the strap braces on the back.

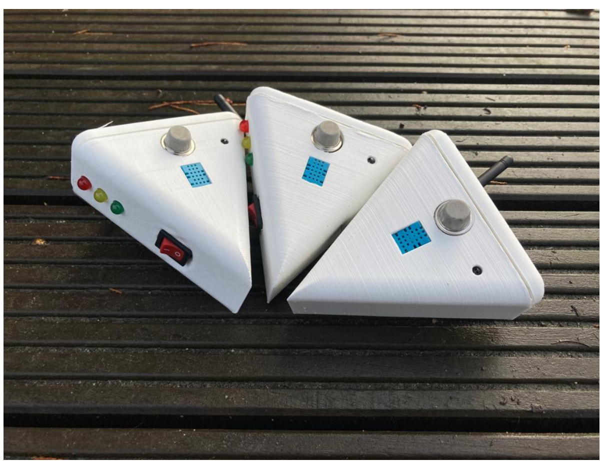
After building the casing, the corresponding components are secured in place. The solar panels are thermofused to the top of the casing to create a watertight seal. Unfortunately the nodes are not fully waterproof.

Custom cables are created in order to connect all the individual modules together. Due to limited space in the casing, it is vital to keep the length of the cables as short as possible.

The powering system consists of a 18650 Lithium-ion battery connected to a charge controller and a boost up converter. The charge controller manages the battery, the input of the solar panel and the output to the boost converter, making sure that the battery does not overcharge or over discharge. The boost converter reshapes the 3.2v to 4.2v coming from the battery and controller, into a stable 5v power supply that the microcontroller can work with.

Finally, all the components were soldered together creating an autonomous system. Calculations suggest that the nodes can go without sunlight for five full days, and only take 12 hours of direct sunlight to charge up completely. (See schematic for detailed connections).


IR SENSOR
OUT GND VCC
TEMP SENSOR
VCC OUT GND
COMM DEVICE
OUT OUT
OUT OUT
OUT OUT
VCC GND
SMOKE SENSOR
ANA OUT
DIGI OUT
GND
VCC
G
Y
R
GND
D13 3V3 REF A0 A1 A2 A3 A4 A5 A6 A7 5V RST GND VIN
Arduino Nano
D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 GND RST RX0 TX1
GND GND
VCC VCC
GND GND
VCC VCC

CHAPTER 8: VALIDATION & RESULTS

Communication

Communication testing was conducted in the Abraham Ledeboerpark using three nodes. The central receiver node was set up and the other nodes were moved away from it to test their effective range.

The nodes were first tested individually in an open field to minimize interference. They were then turned on simultaneously to test the effectiveness of the mesh communication. The tests were then repeated in a forest, which allowed for more realistic measurements of the effective range and consistency of the nodes in a forest environment. The ranges, and if communication works through big trees are summarized in table 1.

	Node 1	Node 2	Node 3	Node Average
Open field	25m	100m	100m	75m
Through big tree	✔	✔	✔	✔
In forest	88m	10m	59m	52m

Table 1: Results for the communication testing

In the open field, with reduced interference, the nodes have a larger range and communicate more consistently. In the forest, the nodes suffered from more inconsistent data transmission and a shorter range.

2 outlier results were identified: node 1 had a considerably lower range communicating in an open field, despite having a range of 88 meters in the forest. Node 2 was unable to connect at distances larger than a few meters in the forest, even without any direct tree interference.

At longer distances the node data transmission in an open field of Node 2 and 3 becomes unreliable, and at a distance of 100 meters the connection ceases completely. Node 1 data transmission already wears off at just 25 meters.

In a forest environment, the effective range of the nodes is shorter due to the interference by trees, bushes and leaves.

Fire Detection

Infrared Signaling

Fire size, distance	Node 1	Node 2	Node 3
SF, 90 cm	100%	100%	100%
SF, 140 cm	70%	20%	85%
MF, 140 cm	100%	90%	100%
MF, 185 cm	95%	No detection	100%
LF, 185 cm	100%	95%	100%
LF, 350 cm	50%	No detection	90%

Table 2: Accuracy of signaling during infrared testing, SF = small fire with flames of 11,5 cm high, MF = medium fire with flames of 18,0 cm high, LF = large fire with flames of 24,5 cm high.

As sunlight emits infrared light as well, the nodes detect fire during the daytime when put in direct light. Though, when the nodes are placed hidden they will only signal fire when they are in line with flames. Therefore, the tests were done during the nighttime, when the accuracy of the fire detection could be measured without sunlight interference.

The output of the infrared sensor is binary. Therefore, the measurements from table 1 show the amount of times a 1 was communicated in a timespan of 1 minute without moving the node. So an accuracy of 50% means that the node communicated an equal amount of ones as zeros in a timespan of 1 minute, while being in direct sight with the fire.

Table 2 shows that nodes 1 and 3 have a 50-100% accuracy of detecting fire with the IR sensor when put in direct sight of a small sized fire at 0 to 140 cm distance, a medium sized at 0 to 185 cm distance, and a large sized fire at 0 to 350 cm distance. Node 2 showed a significantly smaller accuracy when detecting from a larger distance. A likely cause was its battery level.

Interference with any objects between the nodes and the fire disables the infrared sensor to sense the fire. Movement of the flames also causes the infrared signaling of the nodes to turn on and off. When the nodes are placed above the fire, they will not catch any sight of the flame. Flames only in direct line with the infrared sensor will cause the nodes to detect the fire.

Smoke Signaling

	Node 1		Node 2		Node 3	
	analogRead MQ-2	ppm	analogRead MQ-2	ppm	analogRead MQ-2	ppm
Inside base value	60	574,22	85	813,48	128	1234,57
Outside base value	58	555,08	80	765,63	122	1177,15
Bit of smoke	110	1052,73	135	1301,56	147	1416,41
Near the fire	168	1607,81	187	1799,22	190	1818,34

Table 3: AnalogRead of MQ-2 sensor and calculated PPM values during smoke testing

Table 3 shows the results of the performed MQ-2 sensor tests. The sensor measures the parts-per-million (ppm) concentration of the air of LPG, i-butane, propane, carbon monoxide, methane, alcohol, hydrogen, and smoke.

The inside base temperature measured by the nodes was about 21 degrees celsius, while the outside base temperature was measured to be around 10 degrees celsius. The results show that the base value of the nodes differ significantly, with the measured value of Node 3 being more than double the value measured in Node 1 for both the inside and outside base value.

The first round of tests were conducted by attaching the nodes to a pole about 1,5 meters above the ground. A source of smoke was put in front of the node where the wind would blow the smoke against the node. The second round of tests were conducted by placing the nodes almost directly above a fire with a lot of smoke production.

The range of measurements differ between the nodes, where Node 2 and 3 measure quite similarly and Node 1 very differently from the other nodes. Node 2 and 3 had a 8,8% and 1,1% difference in measurements for the first and second test respectively. Node 1 and 2 had a 22,7% and 11,3% difference in measurements for the first and second test respectively.

To calibrate the nodes effectively, these sensors need to be tested and calibrated per location as environmental factors like temperature and humidity affect the values in table 3.

Validation Through Comparison

Part of our implementation research was to compare our approach with the approach of other suitable projects and ideas, as well as to validate our testing results and look for potential solutions to problems we encountered.

As was detailed in Chapter 7: Methodology, our nodes work by setting up a wireless connection with each other that creates a mesh. Each node broadcasts into the mesh until it gets passed along towards our main communication node. This limits the nodes in terms of communication speed and connection range, which can be seen in the results. Wireless sensor networks based on ZigBee use gateway router-based communication to circumvent the issues of signal strength and range [40][41]. It also allows the gateway routers to send active requests, which are responded to by passive answers from the nodes, so that any information such as “temperature and humidity at any part of the forest-covered by the network could easily be collected, dealt with and analyzed at any time” [40]. In addition, “to decrease the loss of energy and data packets, a cluster tree network topology structure” [40] was used in the ZigBee based networks. The connection range of nodes inside ZigBee based wireless networks have an average range of 55m for nodes and 65m for gateway routers. These values are similar to the tested ranges for Deez Nodes. However, the amount of data points available were only three nodes, with a range between 88 and 10 meters, compared to the 14 data points in the ZigBee network [41]. In the best case scenario, Deez Nodes will have a better natural communication range, which can be expanded by utilizing ZigBee-like network structures. They claim that “up to ten routers and a coordinator are needed to cover this pine forest. That is, one router per each 3,000 m2 approximately” [41].

At the moment, Deez Nodes relies on each unit being close enough to each other to have at least one network connection, which depending on the foliage density of the forest will result in minimal coverage with maximum number of nodes. Applying the gateway router solution of the ZigBee based networks, paired with the cluster tree network topology, to send data packets to central units which then pass them along a cleared path, should allow for an increase of range in dense forest areas.

For the data collection, Deez Nodes utilize smoke sensors as well as temperature and IR sensors. These values are broadcasted at a regular interval, unless they detect a spike over the norm values. When that happens, they start broadcasting their data in a short interval and the central server cross references these values with data from other nodes and then acts accordingly. This approach is validated by other research papers focusing on forest fire prevention with node based networks, which utilize the same approach to data collection and evaluation [42]. However, other than most nodes, Deez Nodes use solar panels to recharge their batteries which can lead to inaccuracies with temperature and IR sensors. “The results of the model evaluation showed a 100% detection rate when the nodes are not directly exposed to the sun's rays” [42], our tests showed that this is not really a concern for Deez Nodes, considering the sensitivity can be set high enough to register fire at any strength be it in sunlight or not.

CHAPTER 9: CONCLUSION & DISCUSSION

Conclusion

Burning of forests contributes to 4.8 billion tons of carbon that is released into the atmosphere. These fires are often caused by humans to make space for agriculture, most of which is done illegally. Deez Nodes has developed a wireless sensor network to help governments and other organizations combat this issue. The node system monitores forests, detecting possible fires and notifying other nearby nodes towards a central receiver, where the data can be processed and authorities can be notified.

After considering several solutions to monitor forests, the node system was chosen on the basis of being the most versatile one, with the possibility of easily deploying and expanding it into forest areas. Other options like satellite imagery, drones, or soil composition testing all failed in terms of ease of implementation or reliability. A power independant wireless sensor network like Deez Nodes can monitor the forest at all times and won't be impeded by weather changes, battery life, foliage or the cooperation of third parties.

The current prototype is able to detect fires by utilizing an infrared sensor, smoke detector, and temperature sensor. As soon as one out of three sensors measure irregularities from the norm values of a forest, they will alert the central node of these changes. At the current stage, the IR sensor works with high accuracy in a semi-controlled environment at a range of around 1.7m. The smoke and temperature sensors deliver reliable and steady measurements, but they do require calibration before deployment, as humidity and temperature is unique to different environments.

The nodes are able to communicate with each other at distances of up to 100m in open fields and 88m in a forest. Unfortunately, the communication is not very reliable and consistent. The mesh system used also is not that consistent.

The nodes require further development to be able to consistently and reliably communicate detected possible wildfires and slash and burn agriculture over longer distances using a mesh system.

Discussion

The biggest issue with communication is the inconsistency with which nodes connect to the mesh, the effect range varies greatly, which can impact the placement and effectiveness of the nodes.

The maximum range of communication is lower than theoretically expected. The NRF24L01 should have an effective range of 1000 meters in open fields, this is not the case with Deez Nodes. Theoretically we could have expected the range in forests to be around 250-300 meters. While communication range is limited, so is the sensor range.

The effective range of all the sensors are heavily dependent on the environment and circumstances. The range of the smoke sensor, for instance, changes depending on wind. When placed down wind of fire the range will be larger, while when placed up wind the range will be smaller. The influence of temperature and humidity on the smoke sensors will also influence the results significantly, where a warmer and more humid environment will decrease the accuracy of the readings of the sensor.

Similarly, the effective range of the infrared sensor depends heavily on the environment in which it is to be placed, as the sensitivity can be adjusted accordingly. A dense jungle allows for the sensitivity of the sensor to be high, as sunlight is not likely to interfere. In a forest on the northern hemisphere however, where forests are generally less dense, and trees are leafless during the fall and winter seasons, the sensitivity of the sensor has to be lower to prevent sunlight interference.

Besides the range, the nodes currently suffer from an unstable and unreliable communication network, in which each member simply broadcasts information until it gets passed along to the central node, where the data is then evaluated. Switching this approach to a proper protocol that can handle incoming and outgoing traffic, as well as organize the mesh setup, should improve the network performance. Other research projects that use ZigBee have used a collection tree protocol with great success, and pairing this without continuous and active data broadcasting should yield the results that we are aiming for.

The nodes are still in a very early prototype stage, which comes with a handful of issues outside of data collection. The current version of the nodes are made out of 3D printed shells, and the components were bought with a low budget, so certain concessions were made, which in future models can be worked out relatively easily.

For the casing, creating a resin mold, and printing the two halves without seams and with more weather resistant material is the first step. This already should give the node weather and climate resistance that makes it more suitable for the environment that it is supposed to be deployed in. The placement of the antenna should be reconsidered, since the strap braces on the back causes the antenna to be put between the node and the tree. The next step is to buy fewer general sensors, the smoke sensor in the current prototype is a general chemical sensor that can register more gasses than a CO2 sensor, however, this results in a lack of accuracy and reliability. This sensor was chosen due to the cost of a CO2 sensor, and upgrading the smoke sensor should help the performance of fire detection for the node. The current batteries are not fireproof, so with the purpose of the nodes to detect fire the batteries should be changed to avoid pollution through burned up nodes. Additional sensors would improve the versatility and accuracy of Deez Nodes. Tremor detection sensors could help in detecting deforestation efforts through big machines, and adding speakers or buzzers to alarm the surroundings of detected fire is a worthwhile consideration. In order to decrease the size of the nodes a custom PCB could be created, containing solely the connections that are needed, opposed to using an Arduino Nano that has more ports and more functionality than required for a small node that only needs to collect and send data.

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APPENDIX

Appendix A: Code for the sender nodes

```
/* ** This code uses the following code: **
 * **   RF24Mesh_Example.ino by TMRh20   **
 *
 * This code is used for a project conducted by team DeezNodes for
detecting forest fires.
 * The circuit includes a NRF24L01, a DHT11, an MQ-2, 3 LEDs, and an IR
module.
 *
 * This is code for the sender which works in combination with the receiver
of the mesh-network created.
 * The sender will obtain the measured values of the modules and
communicate them via protocols to the receiver.
 *
 * Code written by team DeezNodes
 */

// Include RF24 Libraries
#include "RF24.h"
#include "RF24Network.h"
#include "RF24Mesh.h"

// Include DHT Library
#include "DHT.h"

// Include SPI Library
#include <SPI.h>

// Define constants
#define DHTPIN 4           // DHT-11 Output Pin connection
#define DHTTYPE DHT11      // DHT Type is DHT 11
#define nodeID 1           // The ID we give to a node (this goes up to 255
with the masternode being 0)

// Define connected pins
int greenLED = 10;         // Green LED connected to pin 10
int redLED = 6;            // Red LED connected to pin 6
int yellowLED = 9;         // Yellow LED connected to pin 9
int IRsensor = 3;          // IR sensor connected to pin 3
```

```
int smokeSensor = A1;     // Smoke sensor connected to A1

// Define variables used for LED regulations
int sensorNumber = 0;
int LEDstate = 0;
unsigned long previousMillis = 0;
unsigned long interval = 500;
unsigned long currentMillis;

// Define variables for firedetection
int IRsensorValue = HIGH; // Set IR sensor output value to HIGH
int smokeSensorValue;     // Stores smoke value
int smokeThreshold = 150; // Used as threshold for smoke measuring
int tempThreshold = 40;   // Used as threshold for temperature measuring
int nodeNum = nodeID;     // Identification number of the nodes
float humidity;           // Stores humidity value
float temperature;        // Stores temperature value
float heatIndex;          // Stores calculated heat index
uint32_t displayTimer = 0;
uint32_t fireDelay = 0;

// Booleans used for firedetection
boolean fireIR = false;
boolean fireTemp = false;
boolean fireSmoke = false;

// Setup the DHT-sensor
DHT dht(DHTPIN, DHTTYPE);

// Configure the chosen CE,CS pins
RF24 radio(7, 8); //(CE,CS)
RF24Network network(radio);
RF24Mesh mesh(radio, network);

struct payload_t {
  unsigned long ms;
  unsigned long counter;
};

void setup() {

  Serial.begin(9600);
  dht.begin();
```

```
  pinMode(greenLED, LOW);        // Pin 10 set to LOW (green LED)
  pinMode(redLED, OUTPUT);       // Pin 6 set to output (red LED)
  pinMode(yellowLED, OUTPUT);    // Pin 9 set to output (yellow LED)
  pinMode(IRsensor, INPUT);      // Pin 3 set to input (infrared sensor)
  pinMode(smokeSensor, INPUT);   // A1 set to input (smoke sensor)

  // Set the nodeID manually
  mesh.setNodeID(nodeID);

  // Connect to the mesh
  Serial.println(F("Connecting to the mesh..."));
  if (!mesh.begin()) {
    Serial.println(F("Radio hardware not responding or could not connect to
network."));
    while (1) {
      // hold in an infinite loop
    }
  }
}

void loop() {

  // ------------------- Infrared sensor -------------------
  IRsensorValue = digitalRead(IRsensor); // Get Infrared value

  // Send results to Serial Monitor
  Serial.println(IRsensorValue);
  if (IRsensorValue == LOW) {
    Serial.println("IR sensor: FLAME DETECTED!");
    fireIR = true;
    sensorNumber ++;
  } else {
    Serial.println("IR sensor: NO FLAME");
    fireIR = false;
  }


  // ------------------- DHT Sensor  -------------------
  humidity = dht.readHumidity(); // Get Humidity value
  temperature = dht.readTemperature(); // Get Temperature value

  // If reading fails, try again and send results to Serial Monitor
```

```
  if (isnan(humidity) || isnan(temperature)) {
    Serial.println("Failed to read data from DHT11");
    return;
  }

  heatIndex = dht.computeHeatIndex(temperature, humidity); // Get
calculated heat index in Celcius

  // Send results to Serial Monitor
  Serial.print("Humidity: ");
  Serial.print(humidity);
  Serial.print("%, Temperature: ");
  Serial.print(temperature);
  Serial.print("°C ");;
  Serial.print("Heat index: ");
  Serial.print(heatIndex);
  Serial.println("°C");

  if (temperature > tempThreshold) {
    fireTemp = true;
    sensorNumber ++;
    Serial.println("Temperature sensor: HIGH TEMPERATURE");
  } else {
    fireTemp = false;
  }

  // ------------------- HQ-2 Sensor -------------------
  smokeSensorValue = analogRead(smokeSensor); // Get Smoke value

  // Send results to Serial Monitor
  Serial.print("SmokeSensorValue: ");
  Serial.println(smokeSensorValue);

  if (smokeSensorValue > smokeThreshold) {
    Serial.println("Smoke sensor: SMOKE DETECTED!");
    sensorNumber++;
    fireSmoke = true;
  } else {
    Serial.println("Smoke sensor: NO SMOKE");
    fireSmoke = false;
  }
```

```
  // ------------------- LED regulations -------------------
  currentMillis = millis(); // Get current milliseconds since start program

  if (sensorNumber == 0) { // No fire is detected
    digitalWrite(yellowLED, LOW);
    digitalWrite(redLED, LOW);
  }
  else if (sensorNumber == 1) { // Red LED is bright for fire detection by
1 sensor
    digitalWrite(redLED, HIGH);
    digitalWrite(yellowLED, LOW);
  }
  else if (sensorNumber == 2) { // Red and Yellow LEDs are bright for fire
detection by 2 sensors
    digitalWrite(yellowLED, HIGH);
    digitalWrite(redLED, HIGH);
  }
  else if (sensorNumber == 3) { // Green and Yellow LEDs blink for fire
detection by 3 sensors
    if (currentMillis - previousMillis >= interval) {
      previousMillis = currentMillis;
      if (LEDstate == LOW) {
        LEDstate = HIGH;
      }
      else {
        LEDstate = LOW;
      }
      for (int i = 9; i < 11; i++) {
        digitalWrite(i, LEDstate);
      }
    }
  }

  // Send results to Serial Monitor
  Serial.println(sensorNumber);

  // Restore and upadate values
  sensorNumber = 0;
  mesh.update();


  // ------------------- Fire Detection Protocol -------------------
  // When the nodes detect a fire send a Case F message to the master node
```

```
every 2 seconds
  if (fireIR || fireTemp || fireSmoke ) {
    if (millis() - fireDelay >= 2000) {  // Do this every 2 seconds
      fireDelay = millis();

      // Write returns a boolean value. Here we send the case and the node
ID of the node detecting the fire
      if (!mesh.write(&nodeNum, 'F', sizeof(nodeNum))) {
        checkConnection();
      }
      else if (!mesh.write(&smokeSensorValue, 'L',
sizeof(smokeSensorValue))){
        checkConnection();
      }
      else if(!mesh.write(&temperature, 'M', sizeof(temperature))){
        checkConnection();
      }
      else if(!mesh.write(&IRsensorValue, 'N', sizeof(IRsensorValue))){
        checkConnection();
      }
      else {
        digitalWrite(yellowLED, LOW);
        Serial.print("Send OK: ");
        Serial.println(nodeNum);
      }
    }
  }


  // ------------------- Sensor Value Protocol -------------------
  // Every six hours (10 seconds for demonstration purposes) the sensor
nodes let the master node know they are still connected, they also send
their sensor data
  if (millis() - displayTimer >= 10000) {
    displayTimer = millis();

    // Send a character type message and the node ID
    if (!mesh.write(&nodeNum, 'T', sizeof(nodeNum))) {
      checkConnection();
    }
    else if (!mesh.write(&smokeSensorValue, 'L', sizeof(smokeSensorValue)))
{
      checkConnection();
```

```
    }
    else if (!mesh.write(&temperature, 'M', sizeof(temperature))) {
      checkConnection();
    }
    else if (!mesh.write(&IRsensorValue, 'N', sizeof(IRsensorValue))) {
       checkConnection();
    } else {
       digitalWrite(yellowLED, LOW);
       Serial.print("Send OK: ");
       Serial.println(displayTimer);
    }
  }

  // ------------------- Network ------------------
  while (network.available()) {
    RF24NetworkHeader header;
    payload_t payload;
    network.read(header, &payload, sizeof(payload));
    Serial.print("Received packet #");
    Serial.print(payload.counter);
    Serial.print(" at ");
    Serial.println(payload.ms);
  }
}

// This function is used to check the connectivity to the mesh network
void checkConnection(){
  digitalWrite(yellowLED, HIGH);

  if (!mesh.checkConnection()) {
    Serial.println("Renewing Address");

  // Refresh the network address, if address renewal fails, reconfigure the
radio and restart the mesh
  // This allows recovery from most if not all radio errors
  if (!mesh.renewAddress()) {
    mesh.begin();
  } else {
    Serial.println("Send fail, Test OK");
    }
  }
}
```

Appendix B: Coder for the master nodes

```
/* ** This code uses the following code:    **
 * ** RF24Mesh_Example_Master.ino by TMRh20 **
 *
 * This code is used for a project conducted by team DeezNodes for
detecting forest fires.
 * The circuit includes a NRF24L01.
 *
 * This is code for the receiver which works in combination with the sender
of the mesh-network created.
 * The receiver will receive the measured values communicated by the
sender.
 * After, the values will be sent to the Serial monitor vial protocols.
 *
 * Code written by team DeezNodes
 */

// Include RF24 Libraries
#include "RF24Network.h"
#include "RF24.h"
#include "RF24Mesh.h"

// Include SPI Library
#include <SPI.h>

//Define variables
uint32_t timer = 0; // Timer used to keep track of functions
int nodeID; // Used for the ID of the sensor nodes (1-255)
int smoke; // Used for the incoming smoke sensor data
float temperature; // Used for the incoming temperature sensor data
(returns in celcius)
boolean infraRed; // Used for the incoming IR data (1 = no fire; 0 = fire)

// Configure the chosen CE,CS pins
RF24 radio(7, 8); //(CE,CS)
RF24Network network(radio);
RF24Mesh mesh(radio, network);

void setup() {

  Serial.begin(9600);
```

```
  // Set the nodeID to 0 for the master node
  mesh.setNodeID(0);

  // Connect to the mesh
  Serial.println(mesh.getNodeID());
  if (!mesh.begin()) {
    Serial.println(F("Radio hardware not responding or could not connect to
network."));
    while (1) {
      // Hold in an infinite loop
    }
  }
}


void loop() {

  // Keep the network updated
  mesh.update();

  // Keep the 'DHCP service' running on the master node so addresses will
be assigned to the sensor nodes
  mesh.DHCP();

  // Check for incoming data from the sensors
  if (network.available()) {
    RF24NetworkHeader header;
    network.peek(header);

    // Serial communication protocols
    switch (header.type) {
      // Case F gets send when a sensor node detects a fire, here it sends
its nodeID which can be used to locate the (possible) fire
      case 'F': network.read(header, &nodeID, sizeof(nodeID));
        Serial.print("node ");
        Serial.print(nodeID);
        Serial.println(" has detected a fire");
        break;
      // Case T is case timer, a node sends its checkup and its nodeID
      case 'T': network.read(header, &nodeID, sizeof(nodeID));
        Serial.print("node ");
        Serial.print(nodeID);
        Serial.println(" is still alive and working");
```

```
          break;
        // Case L is case smoke sensor
        case 'L': network.read(header, &smoke, sizeof(smoke));
          Serial.print("smoke sensor value is: ");
          Serial.println(smoke);
          break;
        // Case M is case temperature
        case 'M': network.read(header, &temperature, sizeof(temperature));
          Serial.print("temperature value is: ");
          Serial.println(temperature);
          break;
        // Case N is case infrared detection
        case 'N': network.read(header, &infraRed, sizeof(infraRed));
          Serial.print("IR value is: ");
          Serial.println(infraRed);
          break;
          break;
      }
    }

  // Every 20 senconds send node and mesh information to the Serial Monitor
  if (millis() - timer > 20000) {
    timer = millis();
    Serial.println(" ");
    Serial.println(F("********Assigned Addresses********"));
    for (int i = 0; i < mesh.addrListTop; i++) {
      Serial.print("NodeID: ");
      Serial.print(mesh.addrList[i].nodeID);
      Serial.print(" RF24Network Address: 0");
      Serial.println(mesh.addrList[i].address, OCT);
    }
    Serial.println(F("**********************************"));
  }
}
```