Department of Electrical, Computer, and Software Engineering

The University of Auckland, Auckland, New Zealand

Project Scope, Aims and Objectives, and Literature Review

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1 PROJECT SCOPE, AIMS AND OBJECTIVES

1.1 Project scope

Project 48 focuses on exploring the use of ambient light as a medium for communication in IoT, low-power remote sensing applications. The overall scope is extremely broad, as it mainly falls under the visible light communication (VLC) and ambient light backscattering (ALB) areas of research. This means for the purpose of this project, there are a large range of areas that we could specifically focus on to improve the existing research on these topics. A typical form of ALB is using the sun as the ambient light source. This, and specifically the collection of sunlight to backscatter to surrounding sensors is what piqued our interest.

Although we cannot encode information into the waves coming directly from the sun, we can modulate the reflected light to send and receive messages. Due to the high directionality of sunlight, our specific aim for this project is to design a system that utilises some sort of sun tracking algorithm to mechanically align itself with the sun as it moves throughout the day to maximise the amount of sunlight available for backscattering. The movement will likely be implemented by a low power motor, ideally powered by a small solar panel that will also benefit from the alignment algorithms for power harvesting.

In addition to this, for a practical use case, the overall system would include many sensors with this functionality on board. This means that our implementation must be a multi sensor design (ideally no less than three), and that those sensors are interchangeable, effectively modelling a practical system.

An all round system for a remote sensing application would also have to consider means of communicating effectively during times of limited sunlight (cloudy day, fog, rain) or no sunlight at all (night). While we want our system to still be able to function under limited sunlight, ensuring that it can still communicate at night falls outside the scope of our project (as this would have to be implemented by modulating an onboard LED, which is not considered ambient light).

1.2 Project aim

As mentioned above, our specific aim for the project is to design and prototype a system that utilises sun tracking algorithms to maximise the amount of light that can be encoded and backscattered to form a multi-sensor system that effectively models a practical system.

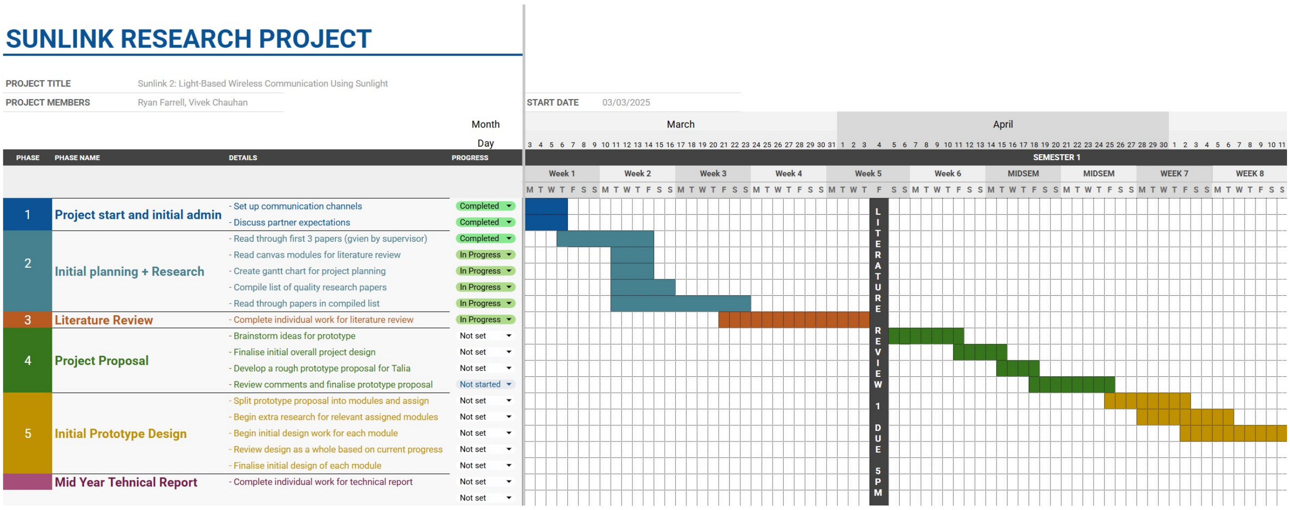
1.3 Project objectives

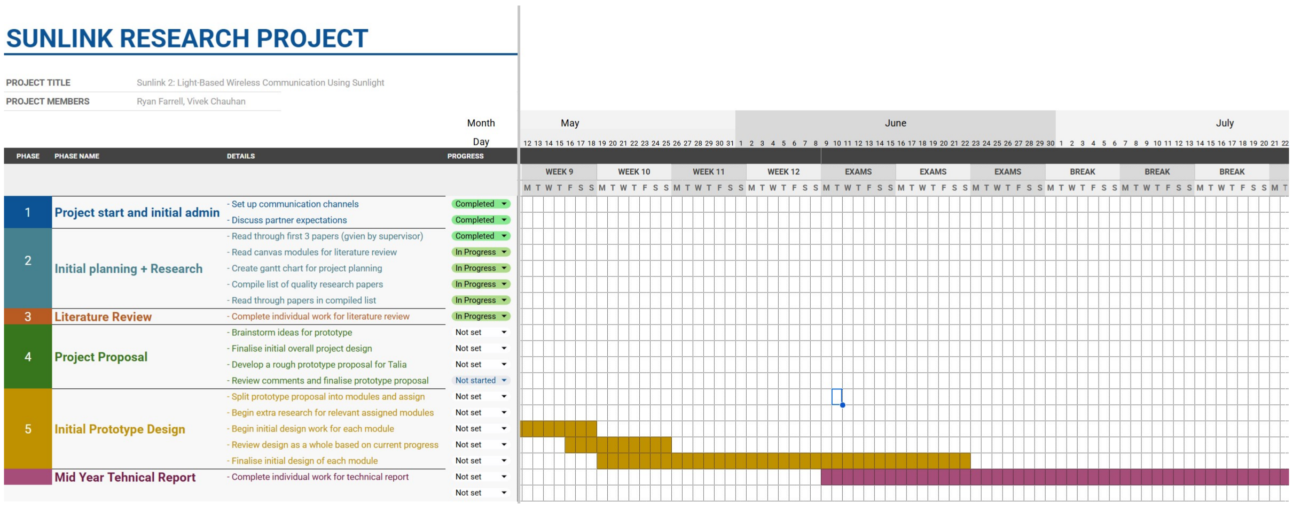
The objectives set out for this project are:

- Review existing VLC and ALB technologies and research to gain an overall understanding in this area.

- Identify the limitations in existing systems and establish areas for improvement, specifically those with a focus on using sunlight as a transmission medium.
- Develop sun tracking algorithms, and use these to control a motor driven system to track the position of the sun as it moves through the sky.
- Develop a working prototype with three fully integrated sensors and test under varying environmental conditions
- Compare the results of our prototype with existing ambient light based alternatives
- Assess the scalability of our design, and specifically the feasibility in remote sensing applications, taking into account power consumption, cost, and overall performance

1.4 Project plan - Semester 1





2 LITERATURE REVIEW

2.1 Wireless communication

Ever since the inception of wireless communication using radio waves in 1894 by Guglielmo Marconi, who developed the first wireless telegraph system capable of transmitting Morse code messages [1], humans have strived to create bigger and better wireless communication systems to improve our daily lives. From the first radio transmission for music and entertainment in 1906 [1] to modern-day smartphones, computers, and televisions, the radio spectrum has been a crutch that everybody today still benefits from. Despite radio frequency (RF) communication being the cornerstone of modern connectivity, which underpins technologies such as WiFi, cellular networks, and satellite communications, it is a finite resource. The radio spectrum is experiencing growing congestion due to the rapid proliferation of connected devices, including smartphones and Internet of Things (IoT) systems. In addition, due to its long-range capability and non-reliance on an available WiFi or cellular network, RF is still a staple for point-to-point communication, with marine and aviation applications being prime examples. The entire radio spectrum for New Zealand is shown in Figure 1.

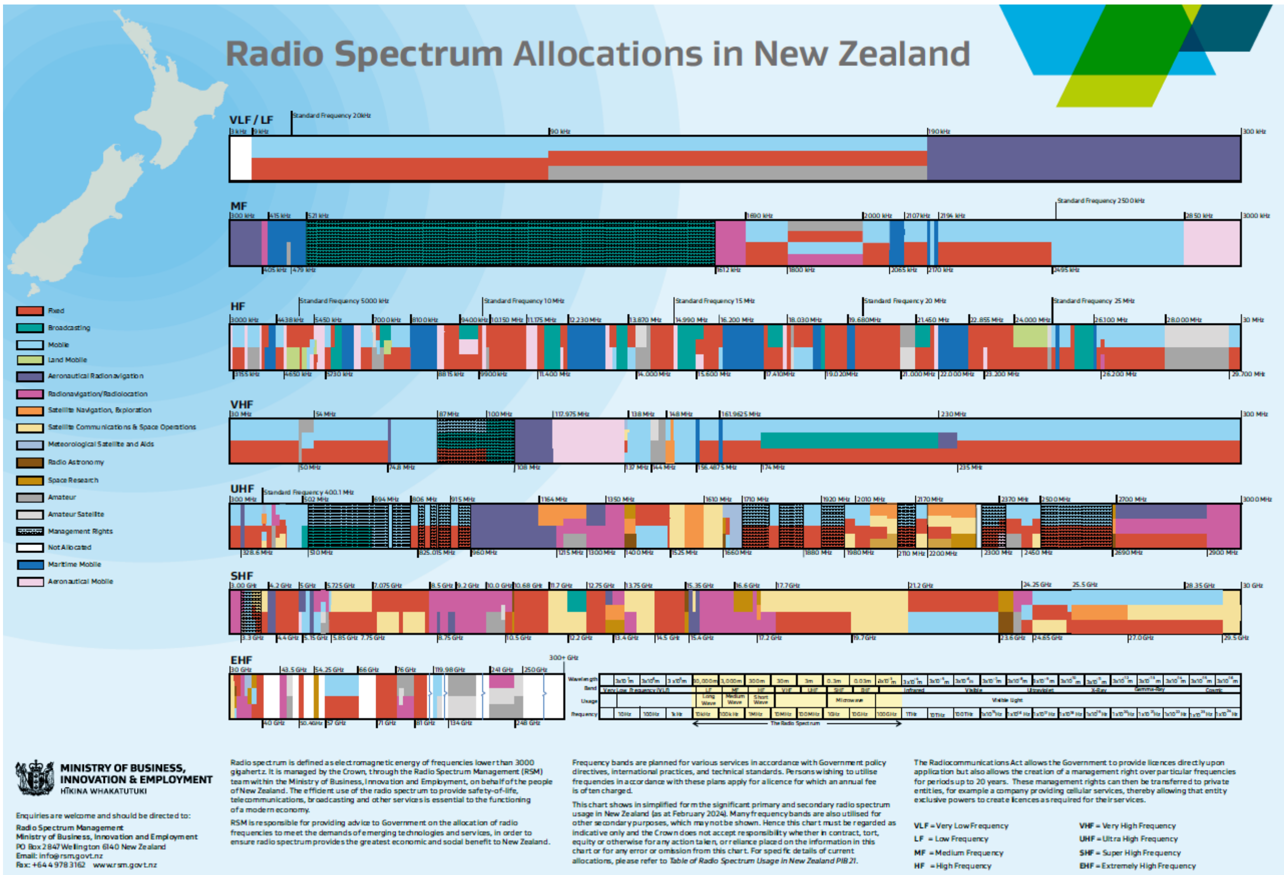


Figure 1: NZ Radio spectrum allocations as of 2025. (from https://www.rsm.govt.nz/about/publications/chart-of-radio-spectrum-allocations-in-new-zealand)

With the long-term sustainability of RF communication in doubt and so much of the existing infrastructure depending on RF communication to function, researchers are exploring alternative communication technologies. One such area of research is visible light communication (VLC). The earliest example of this technology was the photophone, invented by Alexander Graham Bell and Charles Sumner Tainter in 1880 [1]. However, due to the device's limitations, the technology was put to the side to improve radio-based communication once it was invented. The photophone operated based on the modulation of sunlight using a mirror, which is the fundamental idea behind ambient backlight scattering (ABL) applications. All VLC systems function by modulating light intensity, typically from an LED, at high speeds imperceptible to the human eye. This modulation encodes data into the light, which is then decoded by a receiver, such as a photodiode or a camera paired with a processor. This is a fantastic alternative to radio communication because any light source can be modulated to transmit information, which can be utilised effectively in urban environments due to the large number of light sources present everywhere. In addition to this, VLC is unlicensed and hence avoids regulatory restrictions.

There are two different types of VLC systems: active and passive. Any system that generates and modulates a light at the source is considered an active VLC system. The other form of VLC, a passive system, is one that relies on modulating ambient light, massively reducing the power consumption of the system by relying on pre-existing light. This is also the area of VLC that the photophone falls under, as it relies on reflecting sunlight (pre-existing) to communicate a message.

2.2 Active VLC

As described above, an active VLC system is one that actively generates and modulates light for communication, typically using an LED as the source. A receiver, typically featuring a photodiode, is then able to demodulate the light and process the messages, which are sent and received in the form of packets. An example of a potential VLC system in a household environment is shown in Figure 2.

A key example of active VLC is Light-fidelity, or LiFi, a wireless technology capable of transmitting data up to the Gb/s range [2] using a single LED. First introduced in 2011 by Professor Harold Haas, LiFi operates in fundamentally the same way as any typical VLC system. There is an LED as the transmitter, which is modulated at very high speeds, a photodiode at the receiver, and a processing unit to decode the received data. It presents a light-based alternative to WiFi, which works on the radio spectrum to transmit data at high speeds to connect devices to the Internet. LiFi could effectively work in the same way as WiFi, with the added security benefit of LiFi operating via visible light, which cannot penetrate walls the same way radio signals can, making it suitable for creating highly secure home networks or in security and defense applications. Another advantage of LiFi systems is that due to operating on different spectra, they are not interfered with by, nor do they interfere with, RF signals. This feature makes it ideal for use in RF-sensitive environments such as airplanes and hospitals.

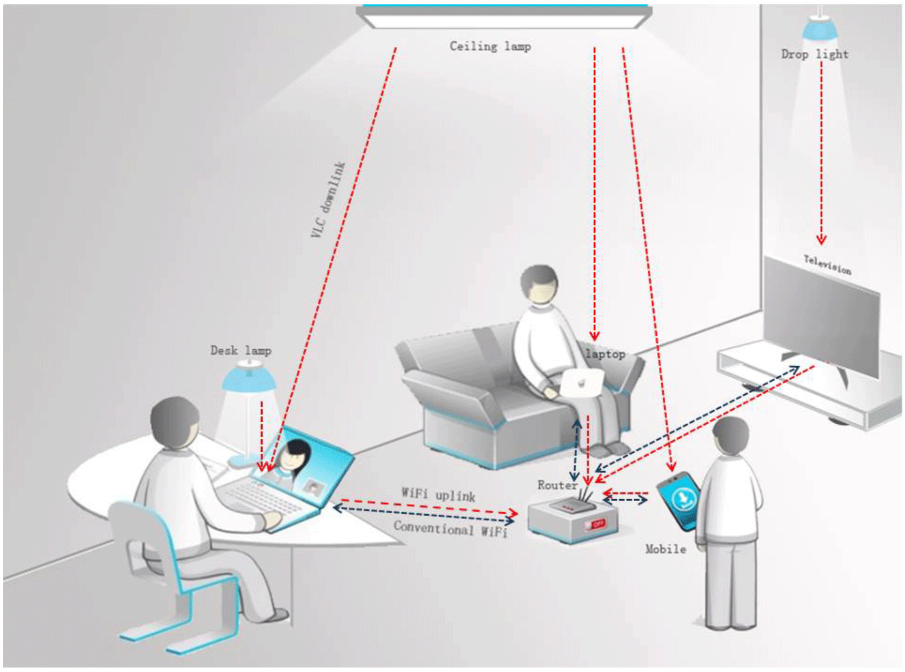


Figure 2: An example of an active VLC system in a household environment. From https://www.openpr.com/news/1618428/visible-light-communication-vlc-market-analysis-reveals-explosive-growth-by-2023-top-key-manufacturers-tokyo-electric-power-kddi-r-d-lab-nec-matsushita-electric-works-nippon-signal-toshiba-samsung-avago-technologies-japan-sony.html

2.2.1 Benefits of active VLC

One of the key advantages of active VLC is that, in most cases, the system can leverage existing LEDs, serving a dual purpose by providing both illumination and high-speed data transmission. This makes it extremely useful for indoor environments like offices that can leverage the existing LED lighting. Active VLC is also beneficial in environments with little to no ambient light, such as deep underwater, where RF waves are ineffective due to high attenuation in water.

2.2.2 Limitations of active VLC

When an existing LED cannot be utilised, an active VLC system must generate its own light, significantly increasing the system's overall power consumption. Additionally, in outdoor environments, especially during the day, the light from an LED would be undermined by sunlight, which is a main concern of interference in active VLC systems. Another limitation of an active VLC system such as LiFi is the line of sight requirement. Due to the transmission medium being visible light, any physical obstructions, such as furniture or structural elements like pillars, can block the line of sight and disrupt the connection.

2.3 Passive VLC

Passive VLC involves modulating an ambient light source, typically using an LCD shutter to encode data, with a reflective surface that backscatters the modulated light to a standard VLC receiver (a photodiode connected to a processor). It's also referred to as visible light backscattering (for visible light backscatter communication, or VLBC systems). Figure 3 shows an example of a passive VLC system from Bloom et al. dubbed LuxLink.

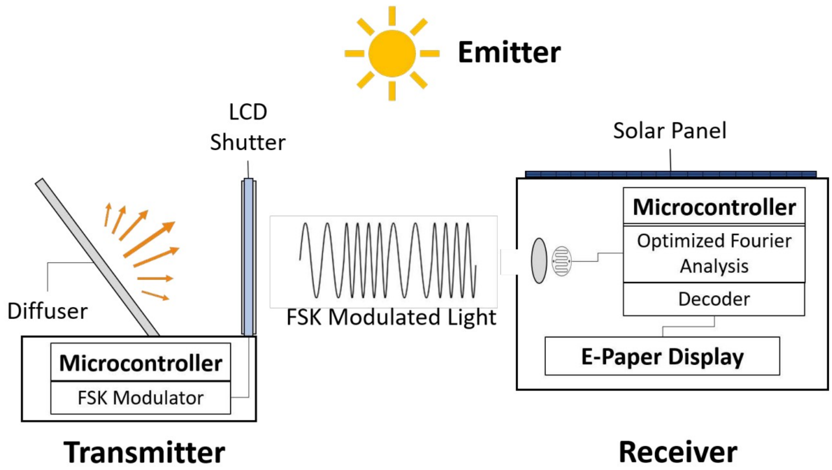


Figure 3: An example of a passive VLC system from Bloom et al. called LuxLink.

The following subsections describe some of the potential applications of passive VLC, followed by the advantages and disadvantages of such systems.

2.3.1 LuxLink

LuxLink [3], developed by Bloom et al. and shown in Figure 3, modulates ambient light from uncontrollable sources (such as the sun and light bulbs) using LCDs to encode information. It then backscatters the modulated light to a phototransistor equipped with a lens and microprocessor for decoding. Inspired by Pixel [4], a system presented in Yang et al., LuxLink uses a polarisation-based modulation scheme to avoid flickering as the human eye is imperceptible to changes in polarization. It is primarily designed to work with sunlight but can work with any ambient light, although interference from other sources (for example, in an indoor environment) can be detrimental to performance. To counteract this, LuxLink used diffuse surfaces and lenses and a robust frequency-shift-keying (FSK) modulation scheme to filter out this interference. LuxLink has an uplink data rate of 80 bits per second and a range of 4-60 meters.

2.3.2 RetroI2V

RetroI2V [5], presented in Wang et al. is an infrastructure-to-vehicle (I2V) communication system that leverages car headlights as a light source and retro-reflective road signs modified with an LCD shutter over the top to transmit and receive information. RetroI2V showcases the other commonly used reflective surface in VLC systems, a retro-reflector, which effectively reflects light almost directly back from whatever direction it comes from. It offers the possibility of a highly integrated system that can be installed on cars to both generate the source of information and receive it all in one. Although it generates the light and may be considered active VLC, it does not modulate the light it's sending; instead, it relies on an LCD shutter to modulate information, which is typically seen in passive VLC systems (VLBC). Performance does not suffer a whole lot from interference as retro-reflectors are designed to reflect light at almost the exact angle it comes in from; however, in situations with multiple signs a short distance from each other, multiple streams of information will be processed at once. RetroI2V worked up to 100 metres and was tested at 250, 500, and 1000 bps.

2.3.3 PassiveCam

PassiveCam [6], presented by Ghiasi et al., leverages a recent emergent technology known as transparent screens, which transform windows into displays. Unlike traditional systems powered by LEDs, PassiveCam operates using ambient light, eliminating the need for an active light source. Contrary to passive VLC systems that use a photodiode or phototransistor at the receiver, PassiveCam builds upon the research area of screen-to-camera communication by utilising a phone camera and software to receive and decode the on-screen information. Essentially, the screen displays a video, which is modulated to be invisible to the human eye but able to be picked up by a phone camera, enabling many users to receive the information simultaneously. PassiveCam modulates an LCD, which, instead of being provided by an LED backlight, which typically consumes about 80% of the system power, is provided by sunlight.

2.3.4 Benefits of passive VLC

Given that passive VLC utilises light from ambient sources rather than generating it, the system design can be reduced to a reflective surface, an LCD for modulation, and a receiver consisting of a low-cost photodiode and microprocessor. Regarding power consumption, the primary power usage in an active system is the LED and modulating circuitry. Passive VLC does not require an LED, and the modulating circuitry consumes less power due to an LCD's reduced modulation frequency capability. This makes it more suitable for low-power applications, where energy efficiency is essential.

2.3.5 Limitations of passive VLC

Some of the key limitations of passive VLC systems are the point-to-point range of the system and the much lower data rate compared with active VLC. Range and data rate are inherently connected because, with an increased data rate, the overall range decreases as the transmission error rate increases. Another significant consideration for most passive VLC systems is avoiding any flickering effects caused by the backscattered rays. To avoid flickering, the light intensity must be modulated at rates greater than 200 Hz [3], or utilise an approach such as in Yang et al. who's work modulated the polarisation as opposed to the intensity. Unlike controllable LEDs, which have fast switching speeds in the MHz range, LCD shutters are limited by their slower response times (kHz), making them unsuitable for high-speed modulation. The range is also impacted by the fact that ambient light can be affected by environmental changes (i.e., overcast vs sunny days), which influence ambient light levels. As a result, the backscattered signal fluctuates in strength, impacting system performance.

References

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