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A Systematic Review of Wireless Infrared Communication

Bachelor's Thesis (9 EAP)

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Lühikokkuvõte:

Viimaste aastakümnete jooksul on nõudlus juhtmevabade kommunikatsiooni süsteemide järele eksponentsiaalselt kasvanud. Nõudluse rahuldamiseks on alternatiivina senistele raadiosagedus-põhistele süsteemidele võimalik kasutada infrapunasagedusel põhinevaid juhtmevabasid süsteeme. Käesoleva bakalaureuse töö tulemusena valmis kirjalik ülevaade infrapuna kiirgusel põhinevatest kommunikatsiooni lahendustest ning materjalid Tartu Ülikooli õppeaine “Sissejuhatus juhtmevaba andmeside turvalisusse (LTAT.04.006)” infrapuna teemalisele loengule. Praktilise osana viidi läbi eelnevalt mainitud video-põhine loeng.

Võtmesõnad:

Infrapuna, juhtmevaba kommunikatsioon, õppematerjalid

CERCS: T180 Telekommunikatsioonitehnoloogia

[Kommentaarid]

Abstract:

The demand for wireless communication systems has increased exponentially during the last few decades. To meet the demand, wireless infrared communication systems can be used as an alternative to the currently used wireless radio communication systems. As a result of this thesis, a systematic review of wireless infrared communication and lecture materials for a course called “Introduction to Wireless Security” were created. The lecture was conducted in video format.

Keywords:

Infrared, wireless communication, study materials

CERCS: T180 Telecommunication engineering

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List of Abbreviations

EMR – Electromagnetic radiation

FIR – Far infrared

FOV – Field-of-view

FSO – Free-space optical communication

IR – Infrared

IrDA – Infrared Data Association

IrLAP – Infrared Link Access Protocol

IrLMP – Infrared Link Management Protocol

IrPHY – Serial Infrared Physical Layer

LAN – Local area network

LD – Laser diode

LED – Light-emitting diode

LOS – Line-of-sight

LWIR – Long-wavelength infrared

MWIR – Mid-wavelength infrared

NIR – Near-Infrared

OWC – Optical wireless communication

SWIR – Short-wavelength infrared

WLAN – Wireless local area network

Introduction

The demand for wireless technologies has increased dramatically in the past few decades. With more clients – both commercial and industrial – demanding products for a wide range of applications, that allow them to wirelessly exchange information, the need for innovation is unceasing.

As of today, the vast majority of wireless communication systems are implemented using means of radio communication. This is mainly because the radio systems have proven to be more reliable and convenient compared to wireless infrared communication systems. However, the benefits of wireless technologies are not strictly limited to user convenience. Time and cost can also be reduced in many of such applications. There are several drawbacks that come with technologies that are using radio frequencies. For example, the allocation of radio frequencies gets harder every year, due to the congestion of the radio part of the electromagnetic spectrum. Contrary to its radio counterpart, infrared offers large unregulated bandwidths. Because of this and many other advantages that infrared has over radio, it has become a potential alternative to radio in a specific range of applications.

The advantages of IR have been known for a long time. However, successfully taking advantage of them was a more recent development. As a result, a large number of standards, classifications and information sources available today can be either outdated or slightly controversial.

The purpose of this thesis is to create structured materials about wireless infrared communication, which help to develop a wider understanding of the technology and its applications. These materials will be used to conduct a video-based lecture for a course called "Introduction to Wireless Security", which is an optional course in the University of Tartu.

The structure of the thesis is the following. The first chapter gives a brief overview on infrared radiation – discovery, properties and applications. The second part covers the principals of wireless infrared communication, different configurations and use cases.

The constructed lecture materials (refer to Appendix I) and the video lecture (refer to Appendix II) is included in the appendices.

1. Infrared radiation

This chapter gives a brief overview of infrared (IR) radiation. The topics that are discussed include different properties and aspects of the IR radiation, the discovery and history of it and multiple applications and uses.

1.1 Definition and Relationship to the Electromagnetic Spectrum

The electromagnetic spectrum is a range of frequencies that include different electromagnetic radiations and their respective wavelengths and photon energies [1]. A representation of the electromagnetic spectrum can be seen in Figure 2.

A wavelength is the spatial period of a periodic wave – the distance over which the wave's shape repeats (See Figure 1). As the wavelength decreases, the frequency increases [2].

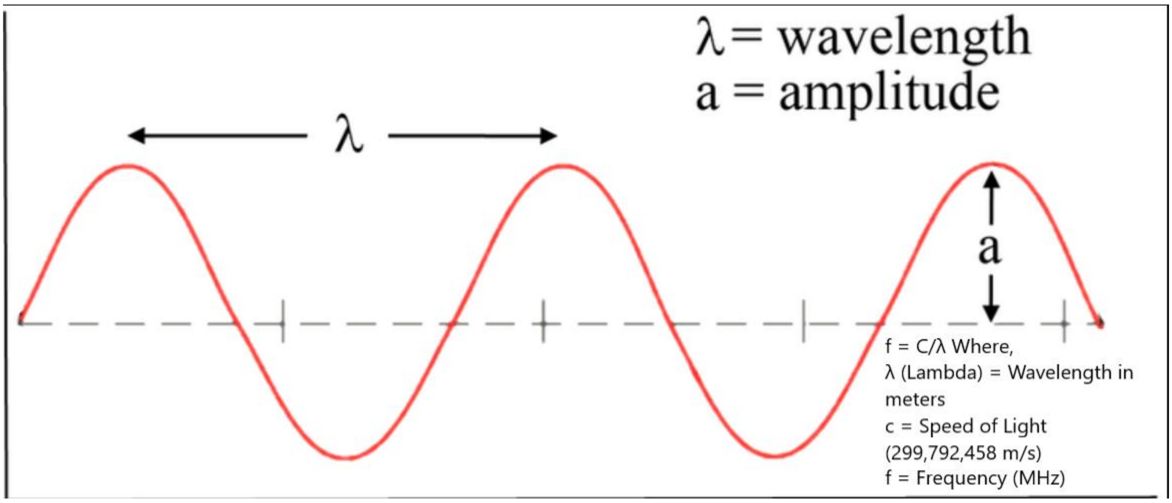

Figure 1. Example of a periodic wave [3].

Infrared is an electromagnetic radiation (EMR), which consists of electromagnetic waves with wavelengths longer than those of light that is visible to the human eye. The range of wavelengths of IR radiation extends from the nominal red edge of the visible spectrum at 700 nanometres (nm) to the starting edge of the microwave section of the electromagnetic spectrum at 1 millimetre (mm). This range of wavelengths corresponds to a frequency range of approximately 430 terahertz (THz) to 300 gigahertz (GHz) [4].

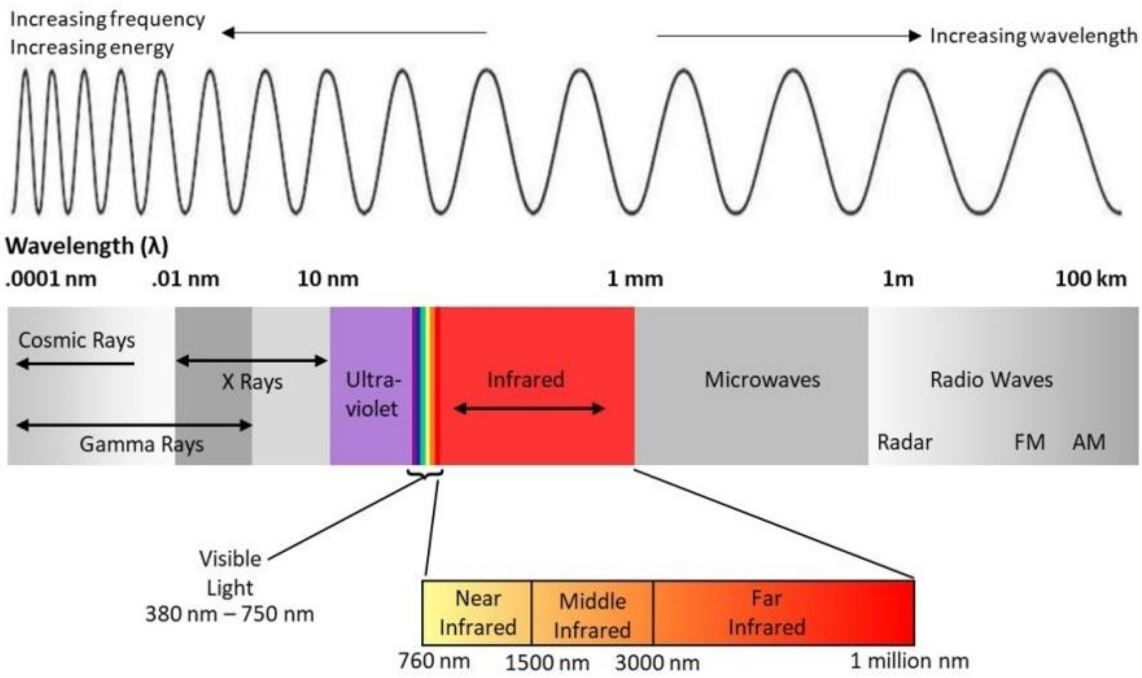

Figure 2. A representation of the electromagnetic spectrum including the infrared light broken down to three sections [5].

The different regions of the IR spectrum will be discussed later on.

1.2 Discovery

According to the private research university of Caltech, the infrared radiation was discovered in 1800 by astronomer Sir Frederick William Herschel. He spent a lot of time studying the light from stars. When he used different coloured filters with his telescope, he noticed that different filters seemed to let different levels of heat through them. To investigate further, he conducted an experiment. In this experiment, he directed sunlight through a glass prism to divide the light into separate colours and measured the temperature of each colour as can be seen in Figure 3. To measure the temperature, he used three thermometers – one for the colours and the other two outside of the spectrum as control samples. The bulbs of the thermometers were blackened to better absorb the heat [6].

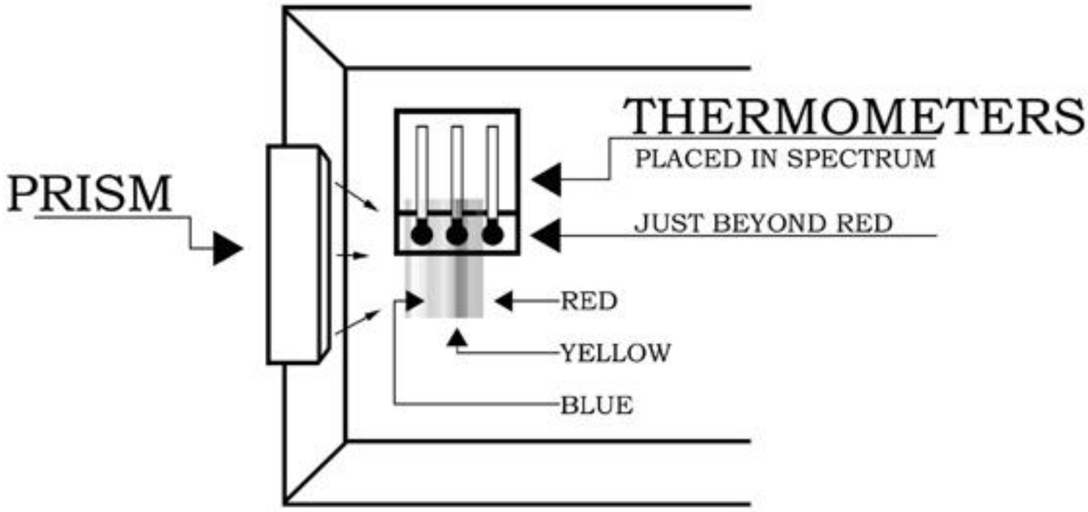

Figure 3. Thermometer setup of Herschel's experiment [7].

As a result of his experiment, Herschel noticed that all the colours' temperature measurements were higher than those of the controls'. Also, he found that the temperatures of the colours increased from violet to the red part of the spectrum. After learning that, he measured the temperature just beyond the red section of the spectrum and he found that this region had the highest temperature of them all. He called them "calorific rays", which is nowadays referred to as infrared radiation. He conducted additional experiments on them afterwards, which revealed the characteristics of the IR radiation [6].

1.3 Natural Infrared

The University of Tennessee states that IR radiation is felt as heat, and is emitted by all objects in the Universe [8]. Some objects that are hot enough, such as fire or the sun also emit visible light. Other objects, like humans, planets or cool stars, that are not as hot only give of IR radiation. In addition to emitting IR radiation, objects also absorb and reflect IR radiation. The same way that different objects emit IR radiation differently, they also absorb and reflect it in different quantities, depending on the structure and colour [9]. Thanks to the previously mentioned properties, one of the most useful applications of the IR spectrum is sensing and detecting objects. With the help of instruments like night-vision goggles or infrared cameras it is possible to detect warm objects and their temperatures. This also applies to astronomy, where devices like optical telescopes can be used to reveal objects that are too cool to detect in visible light and even study the temperature, origins, formation and structure of them [10].

1.4 Regions in the Infrared Spectrum

As mentioned before, all objects emit IR radiation and the emission can be across the whole IR spectrum of wavelengths. Because radiation with different wavelength has different characteristics, a single IR sensing device can collect data only within a specific bandwidth. To study different regions of the infrared spectrum, different sensors are required. Therefore, the IR spectrum is usually divided into smaller sections, depending on the detection technology used for gathering IR data [4].

There are several division schemes that can be used to categorize the IR spectrum. These include [4]:

1. CIE division scheme
2. Astronomy division scheme
3. Sensor response division scheme
4. Thermal radiation scheme
5. Telecommunication bands

One of the more commonly used schemes, according to Byrnes [11] can be found in the following table.

Table 1. Sections of the IR spectrum.

Section name	Wave-length	Corresponding frequency	Characteristics
Near-infra-red (NIR)	750 – 1400 nm	214 – 400 THz	Used commonly in fiber optic telecommunication due to low attenuation losses in the SiO2 glass (silica) medium. Image intensifiers are sensitive to this area of the spectrum. Examples include night vision devices such as night vision goggles.

Short-wave-length infra-red (SWIR)	1400 – 3000 nm	100 – 214 THz	Water absorption increases significantly at 1,450 nm. The 1,530–1,560 nm range is the dominant spectral region for long-distance telecommunications.
Mid-wave-length infra-red (MWIR)	3000 – 8000 nm	37 – 100 THz	In guided missile technology the 3–5 µm portion of this band is the atmospheric window in which the homing heads of passive IR heat seeking missiles are designed to work, homing on to the IR signature of the target aircraft, typically the jet engine exhaust plume. Sometimes referred to as thermal infrared.
Long-wave-length infra-red (LWIR)	8000 – 15000 nm	20 – 37 THz	The thermal imaging region, in which sensors can obtain a completely passive image of objects only slightly higher in temperature than room temperature - for example, the human body - based on thermal emissions only and requiring no illumination such as the sun, moon, or infrared illuminator. This region is also called the thermal infrared.
Far infrared (FIR)	15000 nm – 1 mm	300 GHz – 20 THz	Overlaps with so named terahertz radiation. Transfers energy purely in the form of heat.

The selection of a specific division scheme usually depends on the field of the research. Division scheme, presented by Byrnes will be used throughout this paper.

2. Infrared Communication

Wireless communication is the electromagnetic transfer of information between two or more points that are not connected by an electrical conductor, such as a wire or a cable. Wireless technology permits services, that are impossible or impractical to implement with wires. [12]

The idea of using IR for transmitting information wirelessly between a group of computers was introduced in the late 1970s by Gfeller et al [13]. The proposed system was able to exchange information between terminals, which were located in the same room at low speed over distances up to 50m using near-IR radiation. The terminals were interconnected through an electro-optical satellite located on the ceiling. Since then, there has been an exponential growth of research conducted in the field, which has led to a number of commercial products becoming a reality. The continuous increase of demand for such applications indicate that the technology will continue to develop and expand [14].

In the past few decades, the demand for wireless technologies and the number of applications for them has increased massively. Currently, the main parts of the electromagnetic spectrum used to transmit data wirelessly are the radiofrequency and microwave parts of the spectrum, and the infrared part of it. Although, thus far the most commonly used wireless technologies, like wireless local area network (WLAN) or Bluetooth, use radio waves, IR is gaining popularity every day [14]. IR communication systems can be separated into two main classes (See Figure 4): short to mid-range consumer infrared solutions and devices, most of which comply with the specifications of the Infrared Data Association (IrDA), and medium- to long-range solutions that are developed using the principles of free-space optical communication (FSO). Both of these will be discussed later on in the paper.

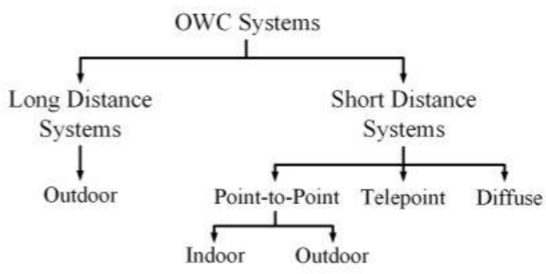

Figure 4. Classification of IR systems [15].

This chapter is mainly devoted to using infrared technology in wireless communication. The overview will offer insight into protocols hardware and software used for infrared communication, different applications that use the technology and a brief comparison to its radio counterpart.

2.1 Free-space Optical Communication

Free-space optical communication (FSO), sometimes also referred to as optical wireless communication (OWC) [15], is a wireless communication technology that uses optical radiation as means to transmit data in telecommunications or computer networking applications [16]. In addition to the NIR part of the IR spectrum, FSO applications also utilize the visible light and ultraviolet bands of the electromagnetic spectrum [15]. The technologies are, however, beyond the scope of this paper.

The technology is used in applications where the physical connections are not possible or impractical.

Some of the best use scenarios for FSO are the following [16, 17]:

1. Short-term wireless information exchange. Primarily IrDA systems.
2. Wireless local area networks (WLANs). This can be an alternative or an upgrade extension to existing LAN technologies.
3. LAN-to-LAN connections for high-speed network access in a city, a metropolitan area network or on campuses.
4. Wireless I/O control devices, such as remote controls and remote electronic keys.
5. Speedy service delivery for high-bandwidth access to optical fiber networks.
6. Temporary network installation.
7. Quick reestablishment of high-speed connection (disaster recovery)
8. As a safety add-on to fiber connections.
9. Extra-terrestrial communication, including spacecrafts and elements of a satellite constellation.
10. Inter- and intra-chip communication.

2.2 The Infrared Data Association

The Infrared Data Association is an industry-driven interest group of manufacturers that was founded in 1993. IrDA developed a set of standards for transmitting data using IR, which features specifications of a large set of protocols for wireless IR communication. The developed standards give different specifications for short-range links ranging from 6cm to 1m [18]. A summary of different IrDA standards including their data rates are shown in Table 2.

Table 2. A summary of IrDA standards and data rates.

IrDA Standard	Data Rates
Serial Infrared	2.4 – 115.2 kbps
Medium Infrared	0.576 and 1.152 Mbps
Fast Infrared	4 Mbps
Very Fast Infrared	16 Mbps
Ultra Fast Infrared	Up to 100 Mbps
Gigabit Infrared (Giga-IR)	512 Mbps and 1.024 Gbps

The two key features for IrDA-based technology are low cost and low power consumption [19].

The IrDA protocol stack consists of multiple different layers as can be seen in Figure 5 [18].

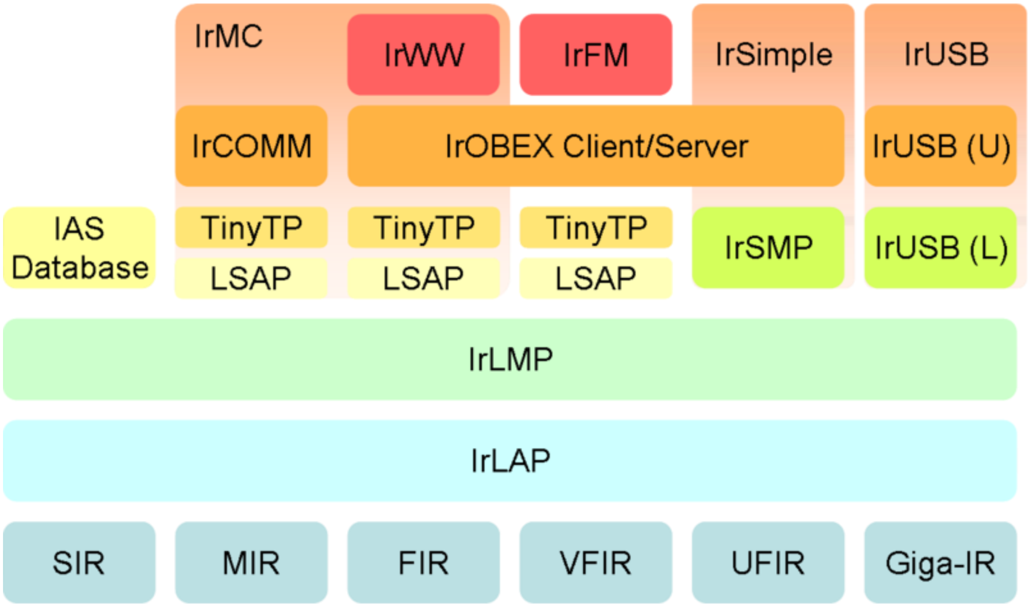

Figure 5. The IrDA protocol stack layers [20].

The mandatory IrDA *Serial Infrared Physical Layer* (IrPHY) describes protocols for the physical layer of the IrDA-based technology, which includes different components like link definitions, and modulation and coding techniques. Different modulation and coding schemes are used for different data rates, which can reach up to 1Gbit/s for a described protocol that is called GigaIR. The GigaIR also defines new usage models that support link distances up to several meters [18].

The mandatory *Infrared Link Access Protocol* (IrLAP) forms the second layer of the specifications. In this layer the most important specifications are access control, discovery of potential communication partners, establishing a reliable bidirectional connection and distributing roles between devices. Devices are divided into secondary devices and a primary device, which controls the secondary devices. A secondary device can only transmit data if it is allowed by the primary one [18].

The third mandatory layer is the *Infrared Link Management* Protocol (IrLMP). It consists of two parts:

- The Link Management Multiplexer, which provides multiple logical channels and allows to change primary and secondary devices.
- The Link Management Information Access Service, which provides a list, where service providers can register their services so that other devices can access them. [18]

There are also a couple of optional layers for the IrDA specification that can improve the IrDA-based systems [18].

The technology described by IrDA was very popular in the late 1990s and the early 2000s with many devices, such as PDAs, laptops and even some desktop computers using IrDA specified IR ports for short-distance IR data exchange [21, 18]. Today most of the IrDA-based technology has been replaced with its radio counterpart.

2.3 Data Transmission Using IR

IR wireless is employed in short- and medium-range communication for both industrial and commercial applications [4].

Like any wireless communication system, an IR communication system consists of three parts: a transmitter circuit a receiver circuit and the channel between them [22, 23]. The data is sent by the transmitter and is captured by the receiver [23]. In short- or mid-range systems, these devices usually correspond to standards published by IrDA [4].

Transmitter

The transmitter is used to convert the electrical input signal to an optical signal that contains the data. The composition of a transmitter can be seen in Figure 6. First, the data is encoded using an encoder device, such as a simple microcontroller. Then, the encoded data is applied to a modulator, which forms a keying modulated signal. Finally, the signal is amplified and transmitted using an appropriate output device [17, 23, 24]. The two most appropriate types of devices are the following: a light-emitting diode (LED) and a semiconductor laser diode (LD). To choose between the previously mentioned devices, several factors should be considered – LEDs have a naturally wider transmission pattern so the line of sight does not have to be as accurate. Also LEDs have lower energy consumption and eye safety is easier to achieve with an LED because an LD has a very narrow and concentrated transmit beam [17]. The main advantages that LDs have over LEDs are their high efficiency, high modulation bandwidth and narrow spectral width, all of which will help to achieve higher data rates [14, 17]. Most of the short-range commercial systems currently use LEDs [17].

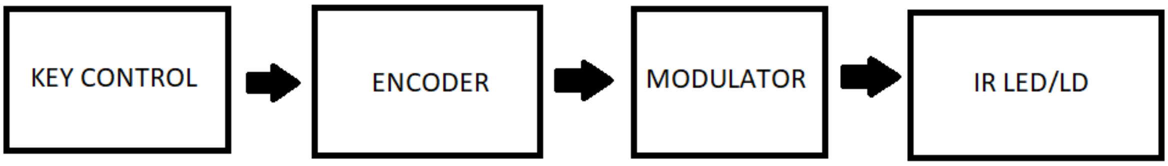

Figure 6. The composition of a transmitter.

Receiver

There are multiple different receiver circuits available developed by different manufacturers but the main working principles of the receiver remain the same for all of them and a typical example can be seen in Figure 7.

The IR receiving unit picks up a modulated IR signal that is emitted by the transmitter. This is usually done by a photodiode. The detected signal is usually too weak so it is amplified and then limited to get a constant pulse signal. After that, the signal is tuned to a certain carrier frequency, which needs to match the frequency of the transmitted modulating signal. This is achieved using a band pass filter. A band pass filter is a device that filters out all irrelevant frequencies. Finally, the optical signal is converted to a digital form using three components: a demodulator, an integrator and a comparator. The function of a demodulator, which sometimes can be referred to as a detector, is to detect whether the carrier frequency is present or not [25]. The integrator defines a minimum time for the burst length and a minimum time between the pulse bursts and prevents the feed-through of short disturbances or spikes to the output [26]. The comparator then observes if the input voltage level surpasses a certain threshold. If yes, then it outputs a high signal, otherwise it outputs a low signal. The comparator outputs a digital signal, which can be processed by a connected microcontroller [27].

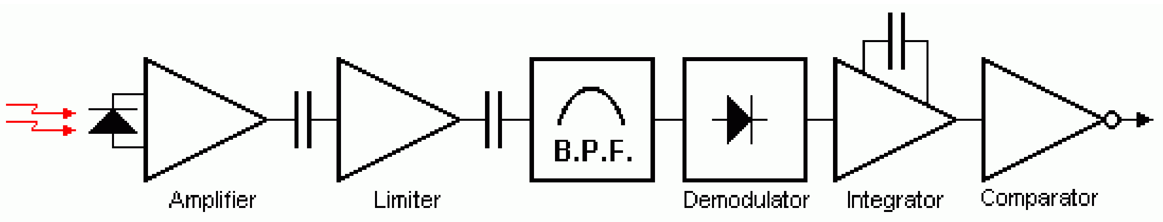

Figure 7. A typical block diagram of an IR receiver [25].

Modulation

As mentioned before, almost every object in the universe emits IR radiation including human beings, light bulbs, sun, etc. All of that ambient infrared noise can interfere with the data transmission. A solution to get rid of most of the noise is signal modulation. To make the infrared connection more robust against other IR radiation sources, the transmission signal is pulsed on-off at a certain frequency [17]. The most common carrier frequency for this is 38kHz, but also other frequencies in the range of 30kHz - 60kHz are commonly used in consumer electronics [25]. The information is modulated on this carrier frequency using on-off keying (OOK) [17], which is the easiest form of amplitude-shift keying modulation that represents bits as the presence or absence of the carrier signal [28]. There are three main modulation techniques for representing one- and zero-bits in remote control systems to extend the OOK scheme [23]:

1. Pulse-distance modulation coding
2. Manchester (Bi-phase) coding
3. Pulse-length modulation coding

In Pulse-distance modulation coding, all pulse bursts have the same length but the time between the bursts is different depending on whether it represents a zero- or one-bit. As seen in Figure 8, transmitting a logical ‘1’ takes a longer time [23].

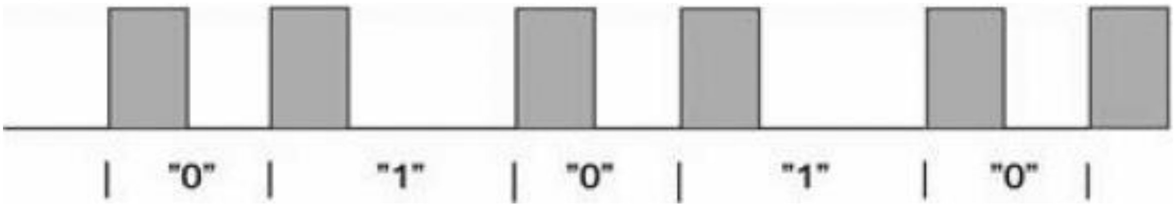

Figure 8. Pulse-distance coding [23].

In Manchester coding, all bits are equal in length, where half of the bit-period is a pulse burst and the other half is a space. In Figure 9 we see a representation of transmitting bit patter ‘11000011’ using the Manchester coding scheme. Transmitting a logical ‘1’ is represented by a space in the first half and a pulse burst in the second half of the bit-period, which means that the signal is transitioned from low to high in the mid-period while a ‘0’ is represented by a high-low pattern [23].

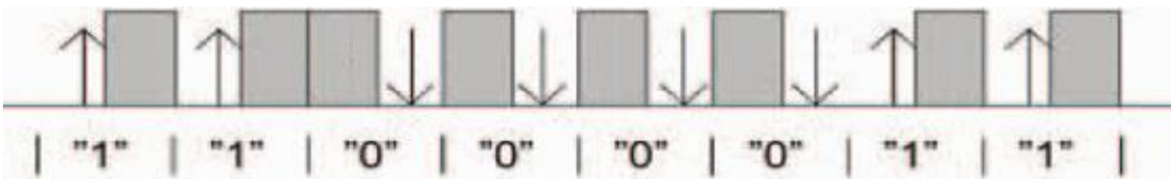

Figure 9. Manchester coding [23].

In Pulse-length modulation coding, two kinds of burst lengths can occur, depending on the value of the bit. In Figure 10 we can see that a logical '1' has a burst length that is 2 times longer than a logical '0'. The spacing length between the bursts is also assigned to a certain value [23].

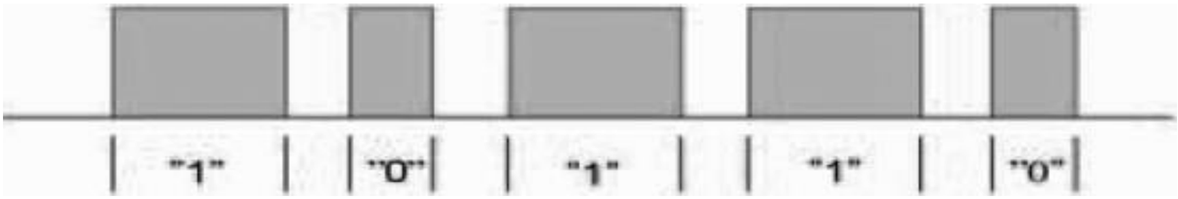

Figure 10. Pulse-length coding [23].

The ambient IR radiation noise problem can also be addressed by choosing an appropriate wavelength for the transmission. According to Li, Y and Ma, C [24], the sunlight influence on the receiver is smaller on higher IR wavelengths (800nm to 1550nm). Therefore, it is good to choose an LED or LD that emits radiation with a wavelength that is in the previously mentioned range. Most commonly, a signal with a wavelength of 940nm is used. Carruthers implies that another important factor to consider when choosing a transmission wavelength is the availability of effective, low-cost sources and detectors. According to him most of the available LEDs and silicon photodiodes are operating in the 800nm to 1000nm range.

Common Modulation Standards

The modulation encoding techniques mentioned are only a base consideration for any IR data transmission system. The final format of the transmission data varies between manufacturers. Such encoded message formats can be referred to as different IR transmission protocols or standards. The most known transmission protocols are SIRC, NEC and RC-5 but there are many more [23].

SIRC

The SIRC protocol was developed by Sony. It features a 12-bit, 15-bit and 20-bit representation of the protocol. In the 12-bit version, 5 bits are reserved for the address code. The address code is mapped to a certain device. In the 15-bit version, 8 bits are reserved for the address. And in the 20-bit version, 5 bits are used for the address and an extra 8 bits are reserved for extended information if needed. The remaining 7 bits are allocated for the command code for all of the versions. All of the versions use the pulse-length modulation scheme for encoding data and a carrier frequency of 40kHz [29].

A SIRC encoded message always starts with a starting pulse burst, that lasts for 2.4ms. After that, the command code is sent in a binary form, where the pulse burst representing a logical one-bit lasts for 1.2ms and the burst representing a logical zero-bit lasts for 0.6ms. An example can be seen in Figure 11. All bursts are separated with a 0.6ms long space period. The command part of the message is followed by the address bits [29].

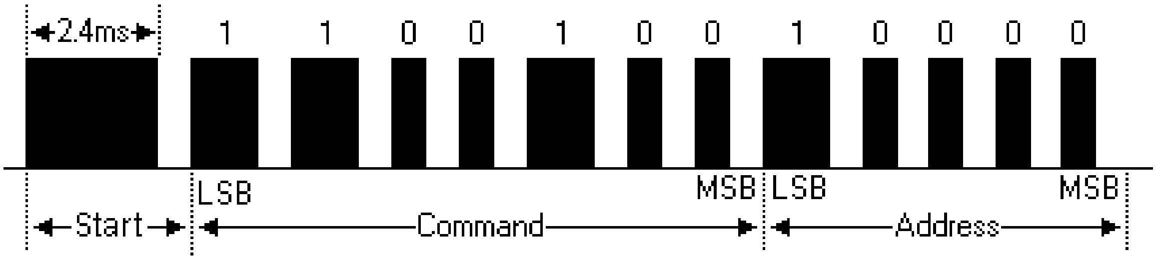

Figure 11. Example pulse stream of a 12-bit SIRC encoded message [29].

NEC

The NEC protocol was developed by NEC (Now called Renesas Electronics). The protocol uses pulse-distance modulation coding and a carrier frequency of 38kHz. Each pulse burst lasts for 560µs. But a logical one-bit takes 2.25ms to transmit, while a logical zero-bit takes 1.125ms. A NEC message, depicted in Figure 12, includes a starting pulse burst of 9ms, which is followed by a 4.5ms long space. After that, 8 bits are reserved for the address, and then another 8 bits to a logical inverse of the address. This helps to verify the message and increase the reliability. Next, an 8-bit long command is sent, and then the inverse of the command code. To signal the end of the message, an additional 560µs long pulse burst is sent [30].

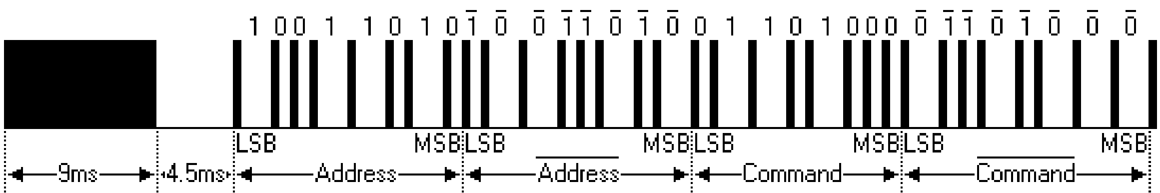

Figure 12. Example pulse stream of a NEC encoded message [30].

RC-5

The RC-5 protocol was developed by Philips. The standard uses Manchester modulation coding and a carrier frequency of 36 kHz. All the bits last equally long – 1.778ms. This means that a logical one-bit in this protocol is represented by a space, which lasts for 889µs, in the first half of the bit-period, followed by a pulse burst of the same length in the second half of the bit-period. A logical zero-bit is represented by a pulse burst in the first half of the bit-period, followed by a space in the second half of the bit-period [31].

A RC-5 encoded message consists of two starting bits S1 and S2 in Figure 13, which are both logical one-bits, followed by a toggle bit T, which is inverted each time a key is released and pressed again. This helps the receiver to distinguish whether a key is being held or pressed down repeatedly. After the toggle bit comes 5 bits that represent the address and the message ends with a 6-bit long command code. Philips has also started using a new protocol called RC-6, which is similar to RC-5 but has much more advanced features [31].

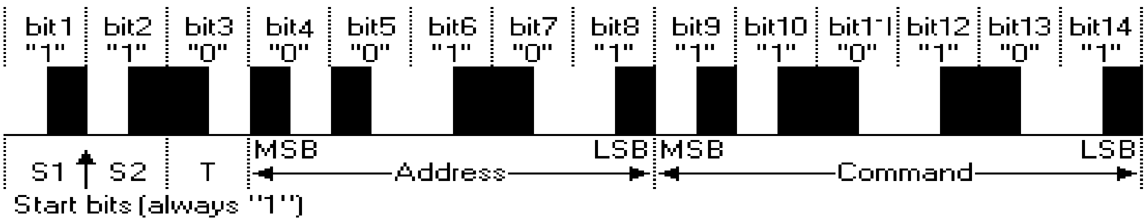

Figure 13. Example pulse stream of a RC-5 encoded message [31].

2.4 System Configurations

There are many different systems that can be implemented using IR communication. All of those systems have their own characteristics and specific requirements. The systems can be arranged in many different configurations. Kahn and Barry [19] proposed a classification scheme for classifying systems with different topologies, which has become one of the most popular and widely used classifications of IR communication systems.

The classification standard by Kahn and Barry use two main criteria to distinguish between different topologies: the directionality of the transmitting component, the receiving component or both (directed, non-directed or hybrid) and whether an unobstructed path exists between the transmitter (LOS) or not (non-LOS). Combining those parameters results in a total of six different configurations (refer to Figure 14) [19].

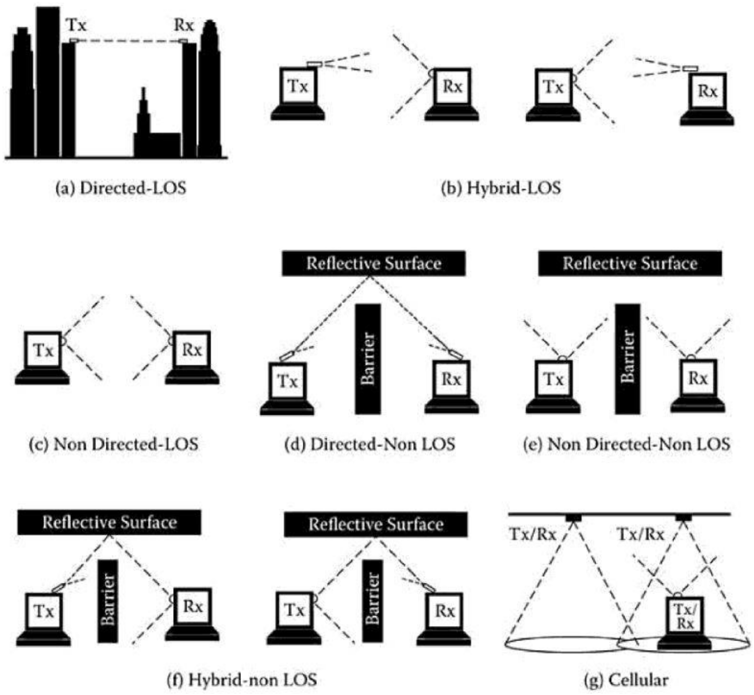

Figure 5. Different configurations of wireless IR links [19].

Regarding the directionality of the transmitter and the receiver, a system is classified as “directed” when the emitted radiation beam from the transmitter and the field-of-view (FOV) are both narrow. This provides great power efficiency due to the directional beam of the transmitter, which furthermore allows the use of narrower FOV receivers, thus minimizing the path loss and ambient light noise. The directed configuration, however has a greater complexity of aligning the transmitter and receiver because of their directionality. This kind of link is also more susceptible to blocking [19].

In non-directed links, wider transmitters and receivers are used with a wide FOV. This is great for increasing the mobility of the system, because it removes the aligning constraint. However, this means that the source power is distributed on a large beam spot size, resulting in loss of performance [19].

Hybrid systems use a different degree of directionality for the transmitters and receiver, combining the advantages and disadvantages of the directed and non-directed links [19].

LOS type links have an unobstructed path between the transmitter and receiver pair. This maximizes power efficiency and minimizes the probability of having undesired energy, coming from a reflection, in the signal, thus reducing multipath distortion and noise problems. Unfortunately, the flexibility of LOS systems is restricted due to the fact that alignment of the transmitter and receiver is required. Contrary to the LOS links, non-LOS links, which are sometimes referred to as diffused links, use the reflection of light from reflecting surfaces, such as a ceiling or walls. This improves the robustness of the link and mobility of the system. On the other hand, they can suffer from multipath distortion [19].

The directed-LOS topology provides highest power efficiency of the configurations, because the power is concentrated into a narrow emission cone. An outdoor FSO system, used to exchange information between buildings is a good example of this configuration. As discussed beforehand, this type of topology includes a couple of problems, like signal blocking and restricted mobility. To solve this problem, Kahn and Barry proposed a special case of system called a tracked system. In a tracked system, the directive transmitter or receiver is moved by mechanical or electro-optical means to maintain continuous LOS [19].

Another special case of a directed-LOS system is the cellular configuration. In the cellular topology, transmitters create spots of energy with minimal overlap. This increases mobility while remaining a decent power efficiency [19]. The system proposed by Gfeller et al [13] had a similar configuration for example.

2.5 Comparison to RF

Wireless IR communication systems offer multiple advantages over its radio counterpart in certain environments. The first significant advantage that IR has over RF is the large bandwidth range that is unregulated and not licenced, which makes developing new systems much faster and cheaper. Contrary to IR, RF-based systems suffer from limited channel capacity. The fact that RF is highly susceptible to electromagnetic interference has resulted in regulations and licencing set by governments, thus making the allocation of radio frequencies for systems harder every year. On the other hand, IR is immune to electromagnetic interference, which makes it the preferred option in environments where interference must be minimized. One example of an environment where this advantage could be utilized is medical facilities. RF LANs can interfere with medical devices, such as pacemakers and infusion pumps, which can have potentially fatal consequences [14].

Furthermore, IR radiation is enclosed by walls (assuming no transparent barriers between rooms), which naturally increases the security of the connection. The radiation beams in IR data transmission travel along a line-of-sight path, making it harder to the intercept. RF signals, however, can propagate through walls, meaning that the data security is at risk, thus encryption is mandatory to avoid information leakage. IR connection links can also be easily encrypted at the software level [14]. This advantage makes IR wireless optimal for short-range links that exchange sensitive information.

Additional advantages of IR over RF systems include the lower cost, small size, and limited power consumption of the components [14].

Despite the advantages, IR has some major drawbacks as well compared to RF. Optical wireless links require a line-of-sight path between the transmitting and receiving parties, which means that they are susceptible to blocking from objects and persons. This can attenuate or disrupt the signal, depending on the configuration of the signal. This can be avoided by adding a tracking mechanism to either the transmitter or the receiver, but it adds complexity to the system. This is not a problem for RF due to its ability to penetrate physical objects. Moreover, wireless IR is affected by the ambient noise other sources of illumination, such as sunlight, incandescent light and fluorescent light, which affects the potential range of the connection link. When transmitted through air in outdoor applications, different environmental limitations apply. Different atmospheric phenomena, such as fog and snow can also cause disruption of the link, further affecting the range and introducing a higher bit error rate [14]. Because of these disadvantages, the applications of IR wireless communications are currently mostly limited to non-commercial experimentations only.

Table 3. Comparison of RF and IR systems.

Property	**RF system**	**IR system**
Bandwidth availability	Low	High
Electromagnetic interference	Yes	No
Security at the hardware level	Low (requires extra encryption)	High
Technology cost	High	Low
Noise sources	Other devices	Sunlight and other ambient light
Power consumption	Medium	Low

Taking both the advantages and disadvantages into account, it seems that, due to the lower reliability of IR, RF solutions will remain the preferred medium for wireless data transmission in the near future. IR systems can be used as an addition to the current RF-based systems to complement some of the disadvantages.

3. Conclusion

The aim of this thesis was to give a structured overview of infrared and the use of it in wireless communication. Theoretical materials about wireless infrared communication were created. The materials were used to conduct a video-based lecture for a course called “Introduction to Wireless Security”.

Based on the results found in this thesis and the discussion, it seems that IR technology has a lot of potential in the field of wireless communication. The potentially high speeds enhanced and immunity to other electromagnetic interference makes it especially appealing in short to medium-range indoor applications and sensitive environments where interference has to be minimal. Unfortunately, because of some the impairments of the IR wireless links, any new systems or applications have not been developed for commercial use since the early 2000s. However, there has been an increased interest in the topic in the past few years, which will, hopefully, address the challenges and difficulties related to wireless IR communication to utilize the advantages that it possesses over the more popular RF-based wireless systems in new applications.

This thesis is mainly concentrated on IR technology. As IR has many similar characteristics to other optical radiations, such as visible light or ultraviolet radiation, further research can be done to combine them in a comprehensive paper about wireless optical communication.

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Appendix

I. Lecture materials

The lecture materials are accessible at:

https://docs.google.com/presentation/d/1uNILv1hOjHaJrdL9VoK4r2VsI91rDO-cObvh6FlErpGA/edit?usp=sharing

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