Optical Wireless Communication – Jump on a New Experience

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Abstract

Currently, there is enormous progress in the field of optical wireless communication. There is the well known IrDA organization approved 1 Gbps Giga-IR standard recently. In addition there are many more players fostering that kind of wireless technology. There is the IEEE 802.15.7 task group founded in 2008 and focusing on visible light communication in combination with state of the art illumination. Data rates are available up to 100 Mbps with link distances up to some meters. Furthermore, there are other organizations like VLCC, ICSA and ISO as well as various scientific approaches to make optical wireless usable in the public.

This paper will introduce different cutting-edge technologies regarding optical wireless communication, research and standardization work as well as provide an overview of various applications where those technologies can be used advantageously. Current application scenarios are, for example, complete wireless terminal solutions for portable devices, Car2X communication, wireless indoor communication – also called “talking light” – for conference rooms, aircrafts, trains, or coaches, inter-machine communication, and many more.

1 Introduction

1.1 Optical Wireless – Basics

The next generation of wireless short range communication systems will be based on several complementary access technologies including optical wireless (OW) communication. That is agreed by both the industry and the scientific community [1]. OW communication uses the infrared and visible spectrum and offers distinctive as well as quite attractive features compared to current RF-based technologies. Thus, OW communication channels provide frequencies of hundreds of THz, where the radio spectrum only provides up to 100 GHz. That results in potentially very high data rates, as is commonly used in today’s fibre optic systems for telecommunications. Additionally, currently, the radio spectrum is getting increasingly crowded, which pushes concerns about electromagnetic interferences (EMI) to the fore. Due to that, various standardization groups and regulatory bodies are regulating the spectrum for particular services and countries. In comparison, the optical spectrum is free and services can be used world-wide without such regulations. Furthermore, optical signals do not penetrate through walls or bodies, which make it possible to use the same frequencies in various adjacent cells without interfering with each other. As a consequence, OW communication provides a high degree of privacy and security that is advantageous to financial and military organizations. In addition, OW communication is highly attractive in areas like hospitals and aeroplanes.

A more controversial point is the type of connection. A majority of optical links are point-to-point and line-of-sight (LOS) connections. Thus, the protocol is less complex and high data rates up to the Gbps range can be provided with a low bit error rate (BER) of approximately 10^{-9}. In consequence, the efficiency of such lean protocols can achieve more than 90% [2]. That means that more than 90% of the overall traffic is user data. Because of that, sometimes, the end-points of the connection – the systems and applications providing or storing the data – are the bottlenecks and not the

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communication itself. For point-to-point communication, the link distance varies from short range to ultra-long range depending on the use cases.

Considering real world applications, the LOS feature can be a challenge, if something blocks the link. That can be avoided by using diffuse communication whereby the light is reflected on opaque surfaces. Principally, diffuse communication is more robust to shading and offers better mobility. It has already been used by well-known low speed remote control systems. For high-speed links the impact of multi-path dispersion, noise and path loss is bigger and limits the maximum speed to some Mbps. Nevertheless, in the last couple of years, there has been much effort to deal with those challenges to provide solutions for diffuse and point-to-multipoint high-speed links. Those solutions often use visible light to "piggyback" data communication on today's cutting-edge LED lighting systems [3]. Due to that, high speed solutions are often uni-directional and also known as "talking light". Then, for the backward channel, another technology has to be used if necessary.

Diffuse communications are often used for indoor applications while LOS communications can be used indoors and outdoors. High speed free space optical (FSO) data links belong to LOS communications but they are not considered in this paper.

1.2 Optical Wireless Applications and Communication Types

OW communications can be used in different application areas in the consumer and medical market as well as in industry. Generally, in those areas the following communication types can be used (Figure 1):

- Mobile-to-mobile (M2M)
- Fixed-to-mobile (F2M)
- Infrastructure-to-mobile (I2M)
- Infrastructure-to-fixed (I2F)

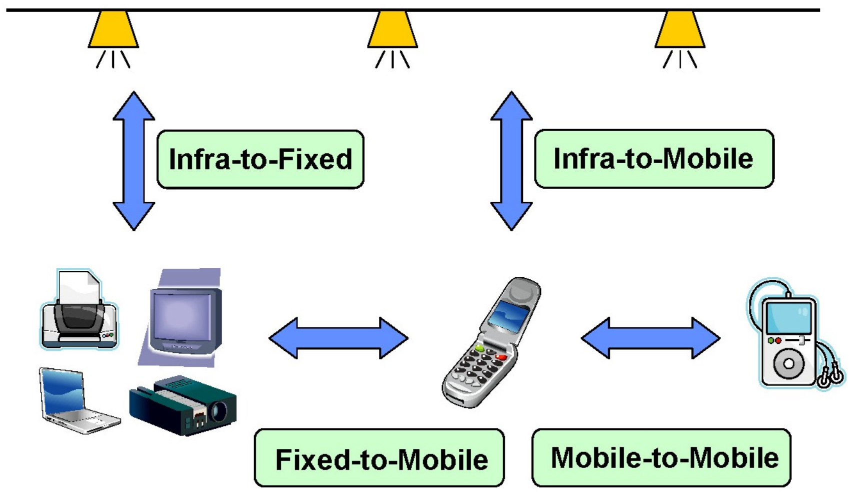

Figure 1: OW communications infrastructure [4]

For M2M communications, the link distance is often smaller than 1 m. Data rates can be up to 1 Gbps. Mobile devices, where OW can be used advantageously, are, for example, mobile phones, PDAs, tablets, e-readers, notebooks as well as portable devices for industrial measurement and telemedicine.

For F2M communications, the link distance is smaller than 1 m. Some few centimeters or millimeters are mostly sufficient. Like M2M communications, the data rate depends on application and can reach 1 Gbps if necessary. The most important applications focused on are file transfer, video streaming, multi-media commerce, device synchronization, or device maintenance. Fixed devices are, for examples, multi-media kiosks, terminals, printers or TVs.

I2M communication requires high power (> 1 W) LEDs to transmit data over distances greater than 3 m in a room and up to 100 m outdoors with data rates between some few kbps and some Mbps. Thus, those LEDs can be used for the purpose of illumination but their secondary duty could be to "piggyback" data communication on to those lighting systems and to act as a communications source. The most important applications focused on are indoor location based services (LBS), indoor navigation, information broadcast, intelligent traffic systems (ITS), or In-Flight Entertainment (IEF) for aeroplanes. I2F communications have similar properties considering infrastructure and fixed endpoints instead of mobile ones.

2 Infrared Light

2.1 IrDA

2.1.1 Physical Layers

Infrared Communication has become well-known over the last two decades, because of the use of IrDA (Infrared Data Association) penetrated devices like mobile phones, PDAs, notebooks, medical devices, wrist watches, or industrial measurement equipment. There, IrDA has provided a short range communication technique to deliver data wirelessly and efficiently over the last one meter. IrDA uses wavelengths around 875 nm and its standards have been well commercialized with data rates from 9.6 kbps to 16 Mbps.

Further efforts on standardizing have brought out higher data rates and additional application layers as well as enhancement of current ones. Today's most important layers are shown in Figure 2. In 2006 the Ultra Fast Infrared (UFIR) standard was published with a net data rate of 96 Mbps and a signaling rate of 120 Mbps [5]. For channel modulation, the dc-balanced 8B10B line code was implemented in combination with 2-ASK (Amplitude Shift Keying) modulation. The maximum link distance is defined with 1 m. At the end of 2009, the latest physical IrDA standard – Giga-IR – was approved [6]. It specifies data rates of 512 Mbps and 1 Gbps. Up to this point, LEDs had been the only infrared light sources for IrDA devices, because LEDs are generally cheap and reliable. They need only simple drivers and have a small form factor. Disadvantages for higher speeds are the maximum switching frequencies of around 622 Mbps [7] and the fact that the transmission power decreases with increasing frequency. Due to that, the maximum data rate and link distance would be limited. To deal with that, it was decided to extend the current track. Besides the common 2-ASK 8B10B coding for 512 Mbps and 1 Gbps a second coding scheme was established that bases on a 4-ASK modulation and an adopted 8B10B codec. Thus, 1 Gbps can be achieved with half of the 2-ASK signaling rate. That opens the opportunity to use LEDs for 1 Gbps instead of more expensive laser diodes (LD). Nevertheless, the 2-ASK 1 Gbps coding can only be used with LDs. Considering the general purpose of IrDA, which means cable and connector replacement, the link distance of Giga-IR is sufficient with up to 10 cm.

Another advantage is the efficiency of that physical layer in combination with IrLAP link access protocol enhancements that relay on well known low BER of around 10^{-9}. Thus, it is possible to increase the frame size up to 64 kByte for Giga-IR. Furthermore, up to 127 frames can be sent without additional acknowledgements in a burst. Incorrect frames are repeated thanks to an automatic block selective repeat (BSR) error recovery scheme [8]. For that reason, only the incorrect frames are selected and retransmitted to keep the overall efficiency high. At the moment, companies and research institutes are working on the Giga-IR commercialization. Target applications with mobile-to-mobile and mobile-to-infrastructure communications are at the fore like mobile multi-media devices, docking stations and multi-media kiosk applications. First components supporting those speeds are announced, for example, in [9] and [10].

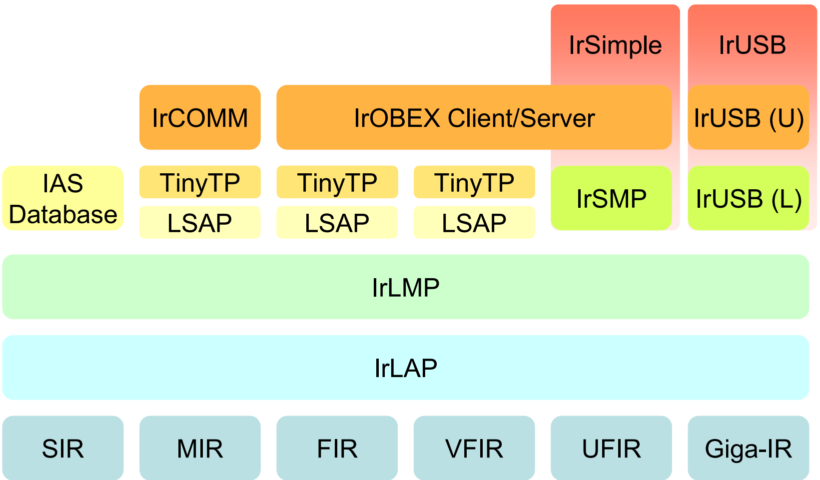

Figure 2: IrDA protocol stack from physical to application layer

2.1.2 IrSimple

IrSimple and the IrSS (IrSimpleShot) is a particular protocol set that was approved in 2008 and provides uni- and bi-directional communications [11]. It defines a reduced discovery and link connection procedure as well as a rudimentary acknowledgement scheme to speed up the transfer of data (Figure 3). Thereby, it is assumed, that only one device wants to send data at the same time. The link distance depends on the supported speeds. For 4 Mbps the typical distance is 3 m. One key application is, for example, to beam a picture using the "point and shoot" principle from a mobile phone or camera to a big TV screen. Another example is a broadcasting application where many mobile devices receive a distinctive data service in parallel from one infrastructure device. At the moment there are more than 311 different IrSimple compliant devices on the market [12]. Those are mostly consumer electronics like cameras, printers, home gateway routers, USB adaptors, mobile phones or TVs.

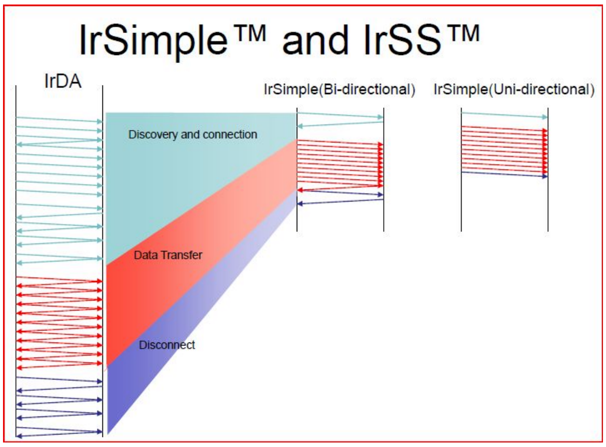

Figure 3: IrSimple (bi-directional) and IrSS (uni-directional) in comparison to legacy IrDA [?]

2.1.3 IrUSB

The Universal Serial Bus (USB) is one of the most widely used cable connections between portable or infrastructure devices and computers. Just as the well known IrCOMM, which emulates serial and parallel data links, IrUSB is intended to provide an USB cable replacement and a transparent communication of USB enabled devices over an IrDA data link. In combination with Giga-IR, the data rates of 480 Mbps for USB 2.0 can be provided sufficiently.

2.1.4 IrOBEX

In the beginning, IrOBEX (Object Exchange) was intended to exchange objects easily between different devices independent of the device's platform and the type of object. Later, IrOBEX was adopted by, for example, Bluetooth, the Open Mobile Alliance or TransferJet by which its interoperability was increased. Within those RF-based and infrared communication technologies, OBEX has been a basis for higher layers or profiles. In 2010, the new IrOBEX version 1.5 was released. The efficiency of object transfer was improved by implementing a Single Response Mode (SMR) [13]. Thus larger objects can be transferred faster. Another improvement was made in the session reliability to allow, for example, an immediate suspension of an ongoing operation. Later in 2010, IrDA and Bluetooth Special Interest Group announced the renewal of the Memorandum of Understanding (MoU) to collaborate in the development of wireless communication and to utilize the IrOBEX specification [14].

2.2 ICSA

The Infrared Communication Systems Association (ICSA) is another standardization group founded in the mid 1990's and located in Japan. ICSA focuses on infrared Wireless Local Area Network (WLAN) systems and its standardization. They published a 10 Mbps infrared WLAN technology for a link distance of several meters and have been working on a 100 Mbps version [15]. In addition they extended their focus to visible light.

2.3 ISO and CALM

The International Standard Organization (ISO) has been working on a family of international standards for Continuous Air interface for Long and Medium range (CALM) which determine a common architecture, network protocols and air-interface definitions for wireless communications using cellular second generation, cellular third generation, 5 GHz, millimeter, and infrared communications. This work is a world-wide collaboration and is conducted by the TC204 working group 16. The aim of work is to provide a standardized information transmission system for the ITS sector whereby vehicle-to-vehicle and vehicle-to-infrastructure communications are at the fore [16]. There, large volumes of data are required for purposes such as safety, traffic information and management (including electronic toll collecting), video downloads to mobile stations for tourist information, entertainment, and navigation-system-updates. In order to support such services, mobile stations need to be able to communicate over longer ranges with fixed stations, and the system must be able to hand over sessions from one fixed station to another. Thus the CALM family of International Standards is explicitly designed to enable quasi-continuous communications, communications of protracted duration, short messages, and sessions of high priority with stringent time constraints.

To realize this, the idea is to connect different communication technologies by means of different physical layers with one network layer. The infrared communication is one technology that is specified in ISO 21214 [17] – the so called CALM-IR. This LOS communication is used with short and medium distances for vehicle-to-vehicle, vehicle-to-roadside, and between mobile equipment and fixed infrastructure points. The data links are established on two channels – around 870 nm and 970 nm. The data rates vary between 1 Mbps and 128 Mbps. Except 1 Mbps and 2 Mbps, the run length limited code HHH(1,13) is used. It is the same code as used for the 16 Mbps Very Fast Infrared (VFIR) IrDA Standard [18]. The code rate of HHH(1,13) is 2/3.

An additional application for infrared communication in ITS systems is the on-board unit (OBU) of the German electronic toll collection systems for heavy goods vehicles. The OBUs are equipped with GPS, GSM and infrared communications amongst others. The infrared Directed Short Range Communications (DSRC) system is used to scan and monitor trucks in motion on the German autobahn. Therefore around 300 toll checker gantries are strategically located through the country. Furthermore, there is a fleet of vehicles of the German Federal Office of Freight. They patrol on the autobahns and check via infrared while driving if the vehicles have paid the toll [19].

3 Visible Light

3.1 Basics

Visible light communications (VLC) is an upcoming disruptive technology now seen as an alternative to RF-based communications in wireless personal area networks (WPAN). It provides the most attractive features of OW communication. An additional opportunity is now arising by using current state-of-the-art LED lighting solutions for illumination and communication at the same time and with the same module due to the ability to modulate LEDs at high speeds.

Thus, those LEDs will be used for the purpose of illumination but their secondary duty could be to "piggyback" data communication on to those lighting systems. This will be particularly relevant in indoor "smart" lighting systems, where the light is always on. Other examples for outdoor use include intelligent traffic systems to exchange data between vehicles and the road infrastructure like traffic lights and control units. Alternatively, the LEDs primary purpose could be to transmit information while the secondary purpose of illumination would be to alert the user to where the data is being transmitted from. In contrast to infrared, the so called feature *What You See Is What You Send* (WYSIWYS) [4] can be used to improve the usability of transmitting data at shorter point-to-point distances between mobile phones or other mobile devices from the consumer, industrial, or medical areas, or even I2M communications. There, illumination can be used for beam-guiding, discovery, or to generate an alarm for misalignment. In comparison to infrared, the angle of view of the transceiver can be reduced. Additionally, this can result in a higher link distance considering a constant transmission power and a constant RX sensitivity of the transceiver.

In 2008, one of the first 120 Mbps VLC demo was shown on a mobile multi-media development platform [20]. This system was developed with the collaboration of Samsung and Fraunhofer IPMS. It does not only include a new physical layer. It also includes all upper layers to provide all necessary services for mobile applications. The channel coding bases on the 8B10B code. Additionally, a full duplex mode and special WYSIWYS principles for discovery, link connection and data transfer were implemented. In a further step, the data rate was scaled up to 320 Mbps to analyze the BER in relation to the link distance. With a data rate of 120 Mbps, the BER was between 10^{-10} and 10^{-9} for link distances of more than 1 m.

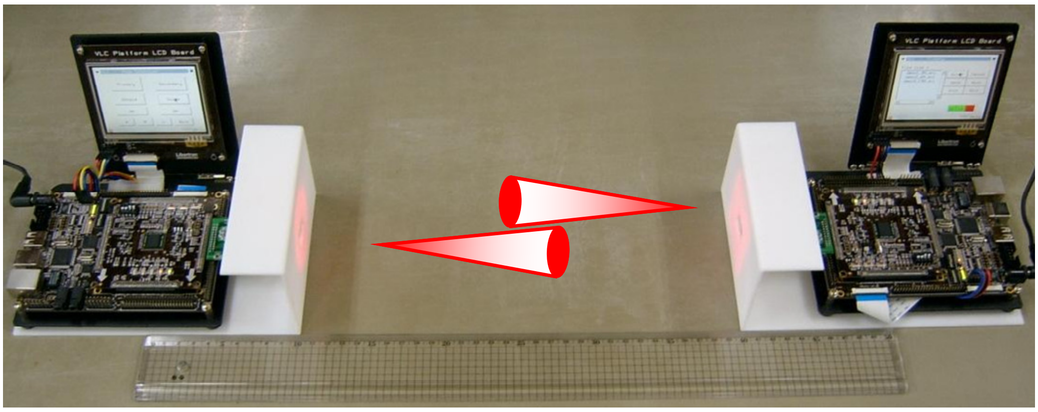

Figure 4: Full duplex 120 Mbps VLC demo implemented in a mobile multi-media platform including upper layers and mobile applications [20]

3.2 VLCC

Driven by the progress of LED technology, visible light communication has been gaining attention in research and development recently [21]. The VLC Consortium (VLCC) in Japan was one of the first to introduce this technology. It is an industry-driven organization that has been working on new visible light communication technologies and on standards. The development of its standards and the progress on visible light LED technology for solid-state lighting has generated very substantial interest worldwide. The main focus of VLCC is indoor I2M and M2M as well as ubiquitous communications.

3.3 IEEE 802.15.7

After establishing a VLC interest group within the IEEE 802.15 wireless personal area networks working group, the IEEE 802.15.7 task group was established by industry, research institutes and universities in 2008. The aim of this task group is to define a standard for visible light communication including M2M, F2M and I2M communications. There, the focus is on low-speed medium range communications for ITS systems and on high-speed short-range M2M and F2M communications to exchange, for example, multi-media data. Due to that, the final goal is two-fold. On the one side are the low-speed techniques to “piggyback” data communication on to the car’s lighting systems. There data rates up to some 100 kbps are considered. On the other side are the high-speed techniques with data rates up to 100 Mbps and beyond [22]. With this application area the WYSIWYS principle can be used to realize where data is transmitted to. The upper layers will support point-to-point and point-to-multipoint connections. One additional challenge for all VLC systems is the flicker of the light while transmitting data. That must be solved by selecting the right channel coding or modulation scheme. It is expected that a first version of the IEEE 802.15.7 standard will be approved by the end of 2010 or the beginning of 2011.

3.3.1 Proprietary Approaches

In addition to standardized technologies, various projects have been funded by industry and the public to gain the experience in visible light communication. In this section, only a few should be mentioned to show what has been happening in this area. One EU funded project is called OMEGA. The goal of this project is to develop an approach for next generation home access networks. The idea here is to merge different wireless technologies to provide a sufficient wireless data rate in every room of a building and for every application or service. Just as with the ISO CALM approach, different physical communication principles – optical and RF-based – should be used depending on their availability over the same upper protocol layers. In this circumstance, one implemented communication technique is a proprietary VLC approach. A demonstrator was shown with an uni-directional physical layer that achieved 125 Mbps at 5 m link distance using white LEDs of lighting systems [3]. This so called “talking light” is supposed to be used in combination with RF-based communication systems directly to deliver more bandwidth in order to up- or downstream high amounts of data. A control channel has to be realized with an RF technique. The overall optical approach is simplified compared to a bi-directional, because either an RX or a TX module is implemented on every side.

In [24] a 500 Mbps uni-directional speed record was announced in 2010 using a white LED. The maximum link distance is mentioned with 5 m, too. Another smart lighting project was announced in 2009 [25] to develop a “talking light” system that should be used in cabins of aeroplanes. Within this project VLC technologies should be developed to open a new range of wireless service applications and in-flight entertainment. Another advantage is that more flexibility is gained in relation to the seating arrangement, because of cable reduction in the seats.

4 Conclusion

In this paper, optical wireless communication was introduced to give an overview of the current progress and cutting-edge technologies in that field. At the moment, there is an enormous progress in that field regarding research, standardization and product development. On the one side are the infrared technologies including recent IrDA standards for data rates up to 1 Gbps and sophisticated application layers that can be used for cable replacement of the last one meter. In addition, there is the ISO CALM standard family for intelligent traffic systems. There, a lot of today’s services are realized via infrared communications. This will be smoothly integrated into a set of other communication technologies which are all together connected to one network layer to finally provide all services over different physical channels depending on its availability.

On the other side are the visible light communication technologies which provide the opportunity for “smart” lighting systems driven by recent progress in white LED technique. Those systems can be used indoors and outdoors where the light is always on. In addition, the WYSIWYS principle was established to visualize the data link and its current status. Besides a lot of proprietary research, the

IEEE 802.15.7 task group has been preparing a standard for both usage scenarios that should be published soon. As a summary, Table 1 shows current infrared and visible light communication technologies as well as important properties.

Table 1: Overview of current infrared and visible light communication technologies

Organisation/ Comm. Type	Target Application	Link Distance	Data Rate	Year[3]	Remarks
IrDA legacy	M2M, F2M	≤1 m	9.6 kbps -1 Gbps	2009	Half duplex, point-to-point
IrSimple/IrSS	M2M, I2M	several m	9.6 kbps -1 Gbps	2008	Bi-/uni-directional, point-to-point, point-to-multipoint
ISO/CALM	ITS	several m	1 - 128 Mbps	2006	Half duplex, point-to-point
ICSA	WLAN	several m	≤10 Mbps	n.a.	Half duplex, point-to-multipoint
VLCC	M2M, I2M	several m	≤10 Mbps	n.a.	Half duplex, point-to-multipoint
Samsung/IPMS	M2M	≤1 m	120 Mbps - 320 Mbps	2008	Full duplex, WYSIWYS, point-to-point
IEEE 802.15.7[4]	M2M, I2M, F2M	several m	100 kbps - 96 Mbps	2011	Point-to-point, point-to-multipoint
OMEGA	I2M	several m	125 Mbps	2009	Uni-directional, only PHY, proprietary
Siemens/FhG	I2M	several m	500 Mbps	2010	Uni-directional, only PHY, proprietary

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