LumiLink

White paper

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1 Introduction

With the rapid growth of the Light Emitting Diode (LED) industry, LEDs are increasingly being used in many different applications. LEDs have excellent characteristics such as low power consumption, small size/high density, high speed response, low cost, long life, and excellence in visibility. Current applications for visible light LEDs include color displays, traffic lights, streetlights, notice boards, automobiles, cellular phones, light houses, computer display/TV backlights, etc. The advent of "white" light LEDs has also allowed the use of LEDs in area lighting, soon to replace legacy incandescent, fluorescent, and halogen light sources. As interest in using LEDs as lighting sources increases, new innovations for lighting products are being developed.

Visible light LEDs also can be used for wireless communication. Because of the fast response time of LEDs, LEDs can be intensity modulated (blinked) much faster than the human eye can perceive. This blinking can be use to communicate digital data, at bit rates greater than 100 Mbps at short distances. An LED can also sense light in a narrow bandwidth slightly lower than but overlapping with its illumination frequency, thus the LED can also be used as a visible light communication receiver.

Visible Light Communication (VLC) proposes to use visible light LEDs for data communication. In most cases, LEDs with the primary purpose of illumination will take on the secondary duty of acting as a digital data communication source; in other cases the LED's primary purpose will be data communication while the secondary purpose will be to communicate visible status to the user.

With the extension of the application of LEDs from the primary purpose of illumination to the secondary purpose of data communication, VLC can be also applied to the NFC area. LumiLink technology is a visible variant of NFC using VLC. With LumiLink, "what you see is what you send". Possible applications of LumiLink are mobile to mobile communication and mobile to infra-structure communication.

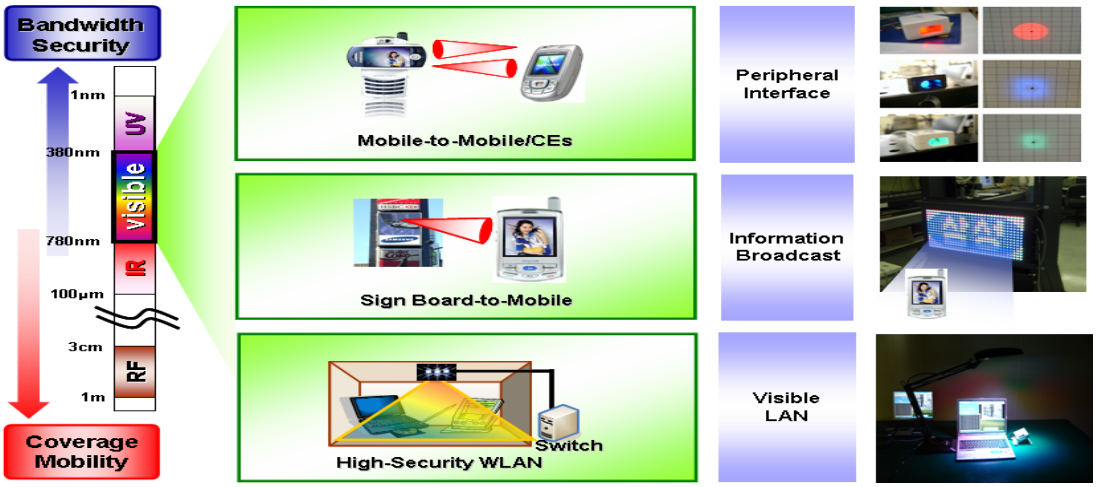


Figure 1. What you see is what you send

2 Possible application areas and use cases

LumiLink technology can be broadly applicable for various devices; for example, mobile, PC, kiosk, payment, multimedia, entertainment, etc. Depending on the application area, LumiLink has some strong synergy effects because of the unique characteristics of VLC. LumiLink can easily communicate with other devices in high speed and high security applications. VLC technology doesn't need to consider RF (Radio Frequency) interference issues, because VLC technology doesn't use the RF medium.

Based on the characteristics of the LumiLink application, LumiLink applications can be classified into two groups; mobile to mobile communication and mobile to infra-structure communication. For mobile-to-mobile communication systems, non-traditional mobile equipment and even home appliances can be included in the mobile communication system. Ever since the appearance of the high-speed access networks, the demand for high speed communication, which can make it possible to transfer the large volume data, has rapidly increased. The transmitting speed of the LumiLink can reach over 100Mbps. Many other use cases can be imagined, such as basic home appliances, e-books, and entertainment using LumiLink.

The LumiLink system has many advantageous features and can be used in many places for the next generation. Figure 2 shows various application of LumiLink.



Figure 2. Various applications using LumiLink



Figure 3. Unique use cases of LumiLink

Figure 3 shows unique usage cases of LumiLink. LumiLink can be used in RF limited areas (such as hospital, aircraft, etc). This characteristic is a strong point of LumiLink technology compared to RF based communication.

3 LumiLink unique features

- User directed communication support in the LumiLink protocol.
  - Visible Frame (VF) will be a key feature of the LumiLink communication protocol. In order to express communication link status or other feedback, using VF can give visible communication to the device user.
    - VF is inserted between data frame and preamble in the communication frame.
    - Brightness intensity of light can be controlled by VF frame length and by changing the proportion of '1's and '0's in the pattern portion of the VF.
    - When data are not transmitted in communication period of data frame, continuous luminescence of LED is possible by using a VF

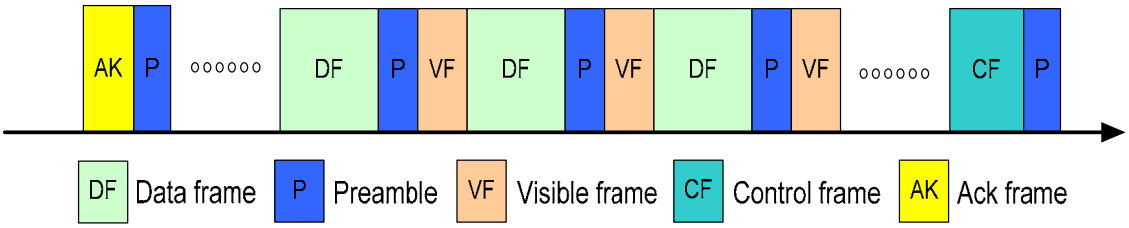


Figure 4. LumiLink application frame

- Having the communication link be visible is useful.
  - Normal RF and Infrared based communications needs the user to estimate where to point the user devices for correct alignment in communication. With the communication beam visible, pointing the device in the right direction to establish the link is not a problem.
  - Laser Diode (LD) or LED is used for the visible transmitter component.
  - Higher security due to the beam visibility
    - The user can see if something unauthorized is in the path of the communication beam, and can see that the beam is sending in the wrong direction.
- Harmless characteristic and non-license for use
  - Unlike RF communication technology, LumiLink technology is harmless in terms of radiation damage and electromagnetic compatibility due to the use of the visible range of the spectrum.
    - It does not cause malfunction of sensitive aircraft equipment or medical instruments since LumiLink has no radio wave interference.

- The radio wave of wireless communication system is ubiquitous because of cell phones and wireless access areas. Also, use of the RF spectrum suffers from frequency allocation problems due to the lack of available radio frequency. LumiLink doesn't have any frequency allocation issues.
- As compared to the radio wave wireless communication, LumiLink doesn't require any license.

- The protocol for visible light channel link and data throughput.
  - Visible light communication link is suitable for near field communication based literally on Line Of Sight (LOS). This communication link has better channel condition than Radio Frequency (RF) channel and can obtain minimum 10^{-8} Bit Error Rate (BER) at experimental communication ranges.
  - If visible frame size is increased, then system throughput can be improved at 10^{-8} BER. But, the excessive frame length can raise problems of large buffer capacity. Therefore the decision of the frame length requires trade-offs between system capacity and frame length.
- Fast and easy connection characteristic
  - LumiLink can support easy devices connection and transfer data between two devices over a short range, point-to-point communication link.
  - Link configuration and speed are transparently negotiated with minimum connect time.

4 LumiLink protocol

- How to control the visibility of visible light communication data link
  - For visibility control of visible light link, link brightness can be controlled by changing the proportion of '1's and '0's being transmitted. Also, the transmitting light source will be off when the source does not transmit data. With this property, visibility of the light source is possible to control by transmitting a special frame.

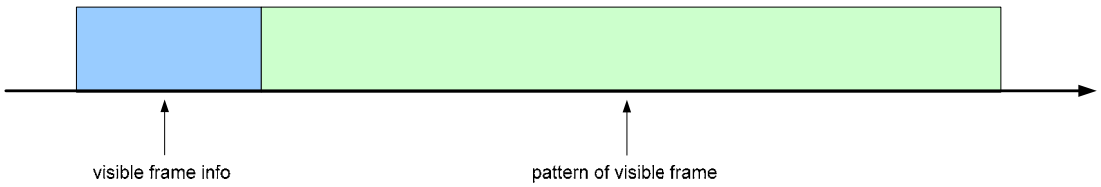


Figure 5. LumiLink application of visible frame

- Visible Frame (VF) in operational mechanism is defined as
  - Data frames, Control frames, and Ack (non-Ack) frames are given priority during transmission, while the Visible Frame fills up the rest of the transmission time.
- Light brightness of the transmission beam can be controlled with the following adjustments:

- Brightness control of the Visible Frame itself is controlled by changing the proportion of '1's and '0's in the Visible Frame
- Overall brightness control is controlled by changing the proportion of visible frames and data frames
  - Strong brightness: long and/or many visible frames and short and/or few data frames.
  - Weak brightness: short and/or few visible frames and long and/or many data frames.

- Composition of VF
  - Contents of the Visible Frame Info field is composed of frame length, frame pattern, frame interval.
  - This information field is used to communicate to the receiver the information about the Visible Frame so that the transmitter and receiver remain synchronized while the transmitting LED brightness is being controlled.

5 Related Technologies

IrDA is a standard defined by the Infrared Data Association (IrDA). It specifies a way to wirelessly transfer data via infrared radiation. The IrDA specifications include standards for both the physical devices and the protocols which are used for communication between devices. The IrDA standards have arisen from the need to connect various mobile devices together.

The table below compares some of the characteristics of LumiLink and IrDA technology, and shows some of the advantages of LumiLink.

	LumiLink	IrDA	UFIR
Link	Visible range	Infrared range	Infrared range
Angle	Narrow (within 10 degree) Compact Beam	Wide (over 30 degree) Spread Beam	Wide (over 30 degree) Spread Beam
Feature	Visible communication link	No visibility	No visibility
Protocol	LumiLink protocol	IrDA protocol	Ultra Fast IrDA protocol
Modulation	8B10B	RZI/4PPM/HHH(1,13)	RZI/4PPM/HHH(1,13)/ 8B10B
Data rate	120 Mbps	16 Mbps	120 Mbps

Table 1. Comparison of LumiLink and IrDA technology

Although LumiLink and IrDA have some similiarities in the communication link and physical structure, LumiLink has a unique communication feature: "what you see is what you send". By

being able to observe the actual transmission beam, LumiLink can have several advantages over IrDA.

IrDA uses a wide beam angle to attempt to compensate for misalignment between transmitter and receiver. Misalignment happens because the user has no way to determine if the devices are properly aligned or not; in the extreme case the devices are so misaligned that no communication will result. With LumiLink, on the other hand, the user can see where the beam is pointed, and thus see when the devices are pointed in the correct direction. Thus LumiLink can use a narrower beam width.

Visible Frame can also be used as feedback to the user to minimize mismatched alignment of devices. In case of alignment mismatch, LumiLink lighting can be flickered using Visible Frame. Thus the user can recognize poor communication link condition by the flickering light.

The narrow beam of LumiLink gives less of an opportunity for eavesdropping; with a narrow beam, little or none of the beam could leak past the receiving device, and thus there is less beam leakage for an eavesdropper to use.

In addition, visibility of the beam gives us an intrinsic security element, because the user can see if an attacker puts an unauthorized device into the light beam.

Also, with this narrower beam width, LumiLink will minimize adjacent device interference. If an IrDA source device wants to connect to another device that happens to be close to a third device, then because of the wide beam in IrDA, the IrDA system design requires interference avoidance protocols. This means that, in order to assure system QoS, the system design for IrDA needs to be more complex for interference reduction. LumiLink, with its narrower beam, will greatly decrease if not eliminate adjacent device interference. Plus, the beam can be easily blocked from illuminating more than one device at once.

One obvious issue with LumiLink systems is the need to avoid interference from other visible light sources (such as the Sun) and multi-path interference from reflections. Noise from ambient light such as sunlight, fluorescent light, incandescent light, etc. is very important issues for the LumiLink system. The right optical filter and modulation scheme are needed to reduce interference from ambient light. For our eye's safety, even with visible light, power limits should be considered in LumiLink.

6 Related standards and references

1) Infrared Data Association Serial Infrared Physical Layer Specification Version 1.4
2) Infrared Data Association Serial Infrared Physical Layer Specification UFIR Version 1.0

6.1 Other references

Ecma International: http://www.ecma-international.org