OVERVIEW FOR OPTICAL WIRELESS COMMUNICATION

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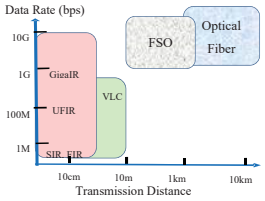
Abstract

With the progress of the Internet and spread of Mobile phones, it is becoming a IoT era that can be gotten large capacity information at any time instantly, and connection to the network has become increasingly important. So far Optical wireless communication system such as infrared rays, visible light, and lasers have been studied and developed. The optical wireless communication system is can be applied to a wide range of fields such as space communication, ground communication, underwater communication, because it is easy to speed up, high confidentiality, no legal regulation and standardized worldwide communication system. In optical space communication system is realized by LDs and LEDs.



This paper introduces the history of development in optical space communication technology using LD and LED current situation and future development.

KEYWORDS: LD, LED, FSO, VLC, IrDA, RoFSO.

インターネットの普及や携帯電話の普及に伴い、瞬時に大容量の情報を得ることができ、ネットワークへの接続がますます重要になってきている。 赤外線、可視光、レーザーなどの光無線通信システムが研究開発されている。光無線通信システムは、スピードアップ、機密性の確保、法規制の規制、世界標準化された通信システムの標準化が容易であるため、宇宙通信、地上通信、水中通信など幅広い分野に適用可能である。 これらの光空間通信システムでは、LD および LED によって通信システムが実現される。

本稿では、LD と LED を用いた光空間通信技術の発展の歴史、現状と今後の展開について紹介する。

OVERVIEW FOR OPTICAL WIRELESS COMMUNICATION

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Outline

- Introduction
- Position of OWC(optical wireless system)
- IRC(Infrared communication system)
- VLC(Visible light communication system)
- FSO(Free space optical wireless system)
- Conclusion

Introduction

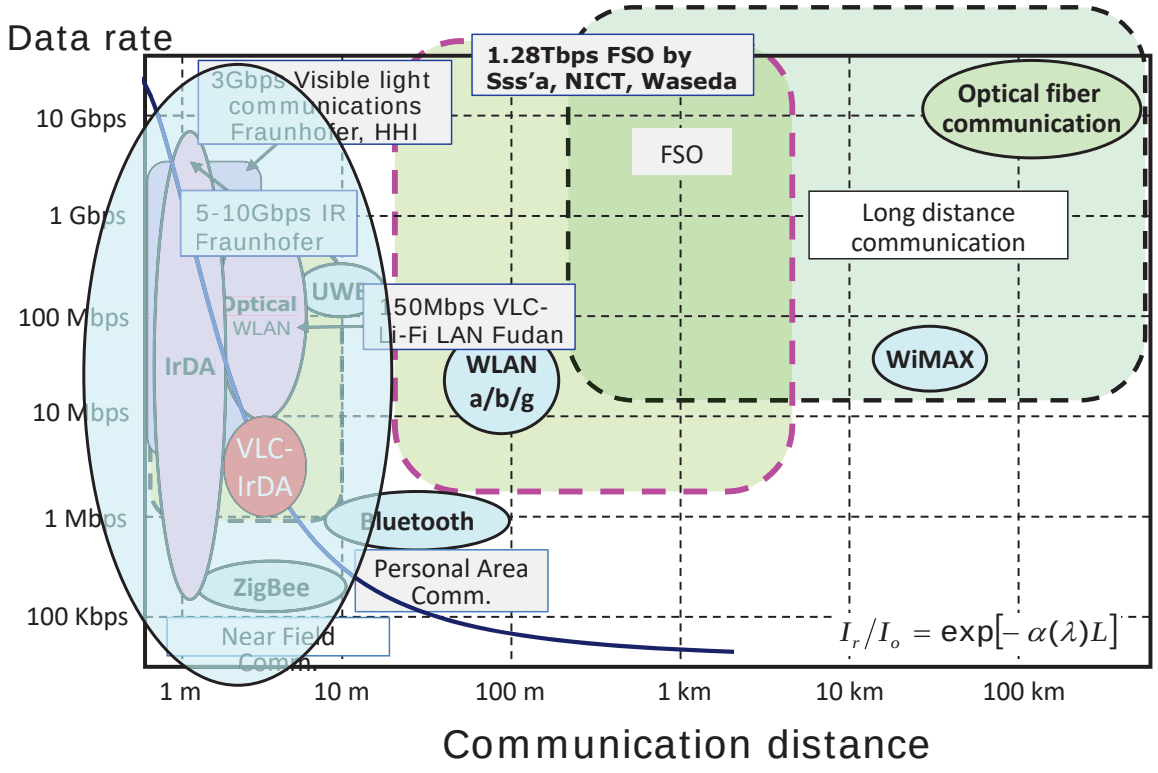
- Changes in the social environment,
  anywhere, anytime, high speed/high quality, easy and seamless,
  various service/application connections are demanded.
  Wireless technology (Radio/Optical) is promising to solve these challenges.

- Radio and optical have advantages and disadvantages, but here I introduce the area of OWC (optical Wireless Communication).
- In the old wireless standard of the microwave relay system, BER≦0.01%/2,500km has been required and the value of the call loss rate is close to the (3%) of the whole communication network or mobile phone.
- **Conventional optical wireless communication has been used as a complementary.**
- Areas where **best effort communication, or standards** can be relaxed.

Characteristics of OWC

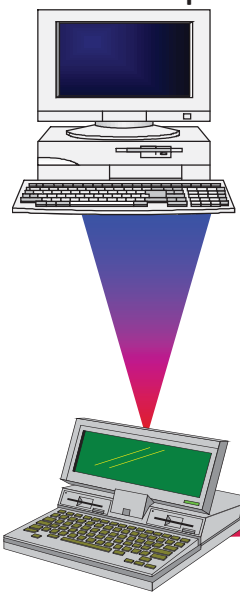
- The radiation beam of light travels straight at a
  - by **wide angle** (short distance) or
  - by **narrow angle** (long distance) communication.
- Wide range of application fields of light include
  - space(**FSO**), ground(**FSO, VLC, IRC**), underwater(**VLC**)
- Further research on
  - transmitter/receiver **optical components**,
  - lightwave **propagation technology** etc. are important
- For popularization, **Standardization** is also important.

Current trend for OWC in Communication Distance and Speed



Appearance of Infrared Data Communication

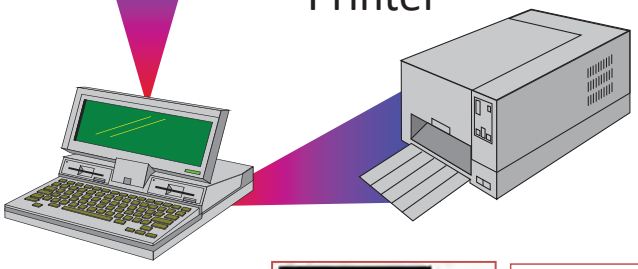
Desktop PC



Mobile terminal boom in the 1990's:
Newton (PDA),Electronic notebook ,Personal Communicator:
Start : **Windows 95 OS machine**

Information exchange and printout with the desktop PC (conventionally cable connection, FD exchange)

Printer



Focusing on infrared technology which has been widely used for remote control of home TV, stereo, air conditioner and so on for the past, it is applied for IR communication.

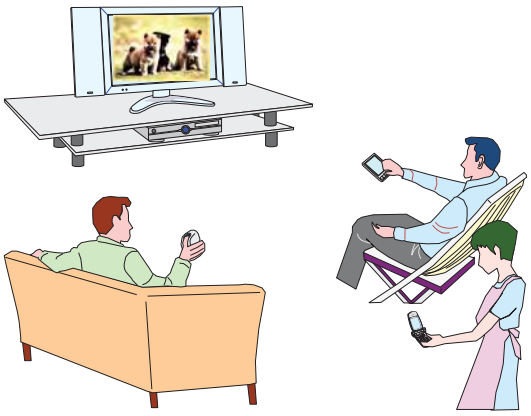
Mobile PC

Infrared Data Association

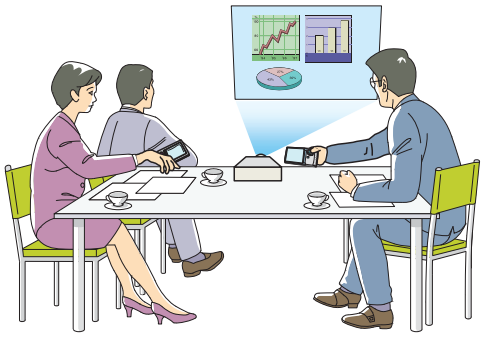
IrDA launched: In 1993 the consortium,
De facto standardization organization
Members: approx.100 (U.S.), 43(Japan)

User Scene

Showing pictures on the Big Screen.

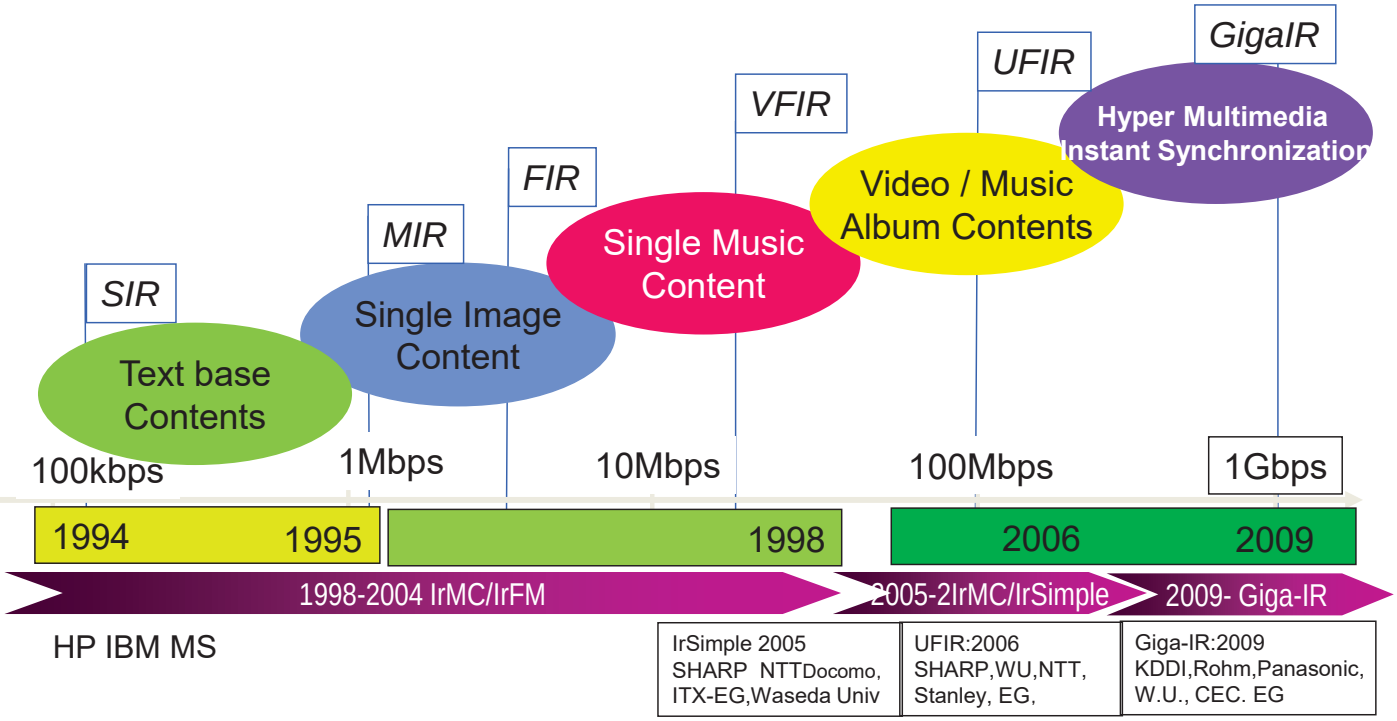


Using presentation data from own PDA or cell phone.

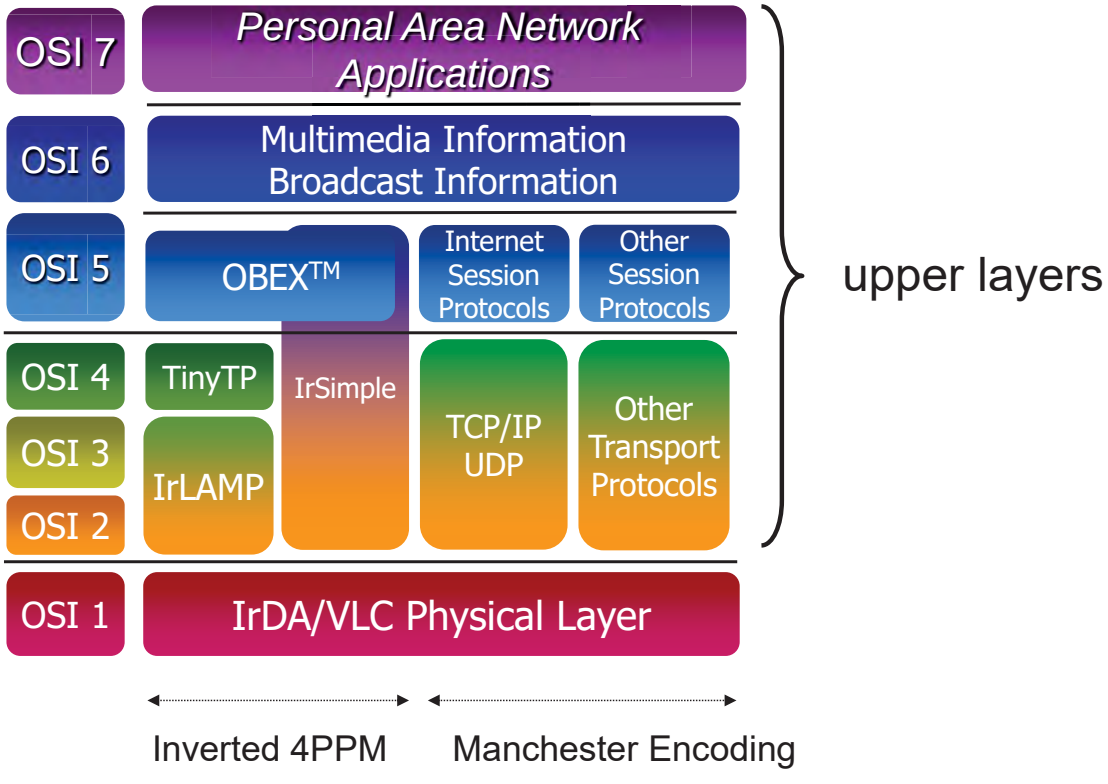


IrDA Roadmap

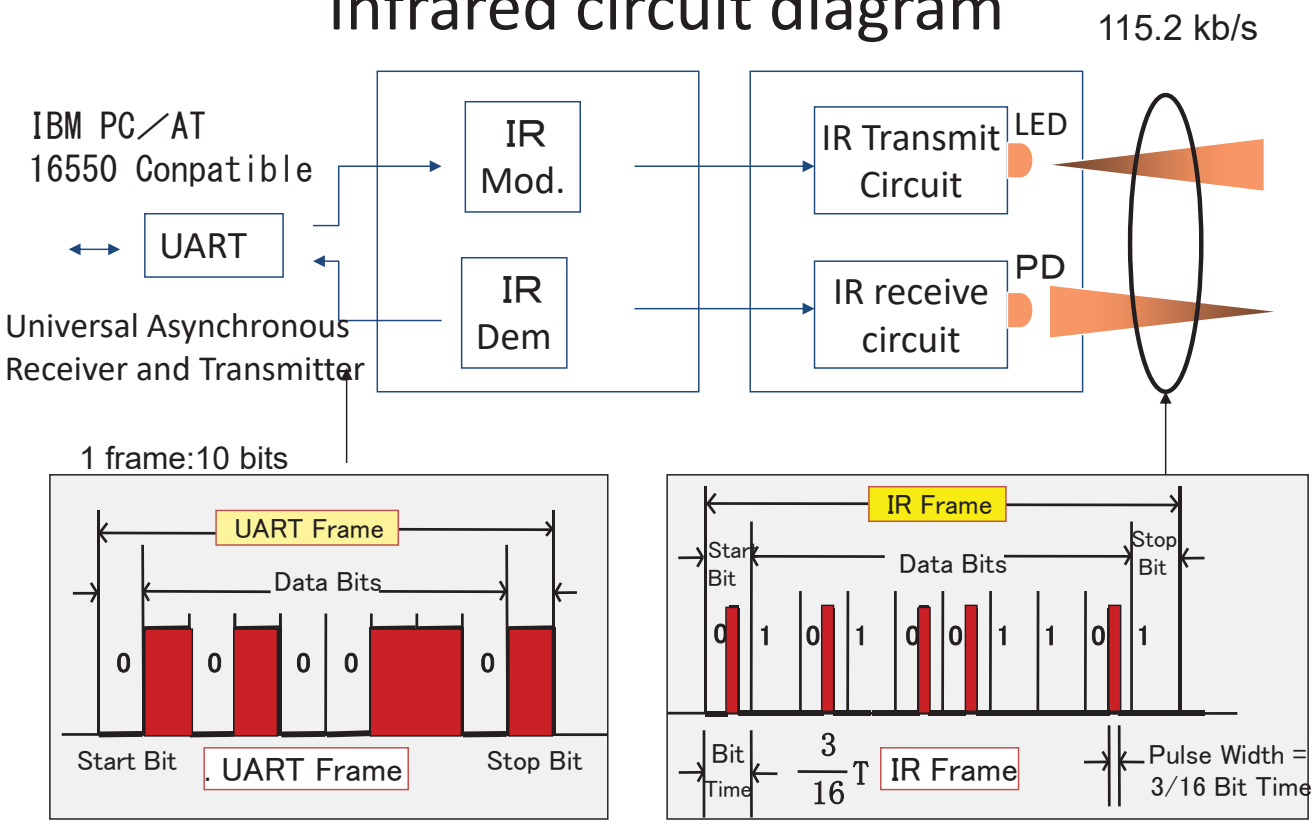
short distance/1m/high speed



IrDA/VLC Protocol Stack

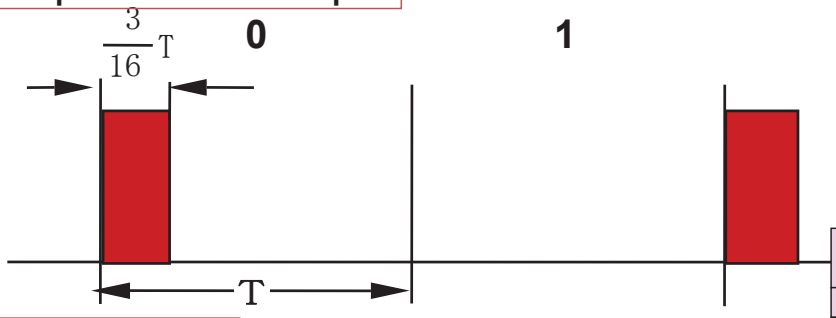


Infrared circuit diagram



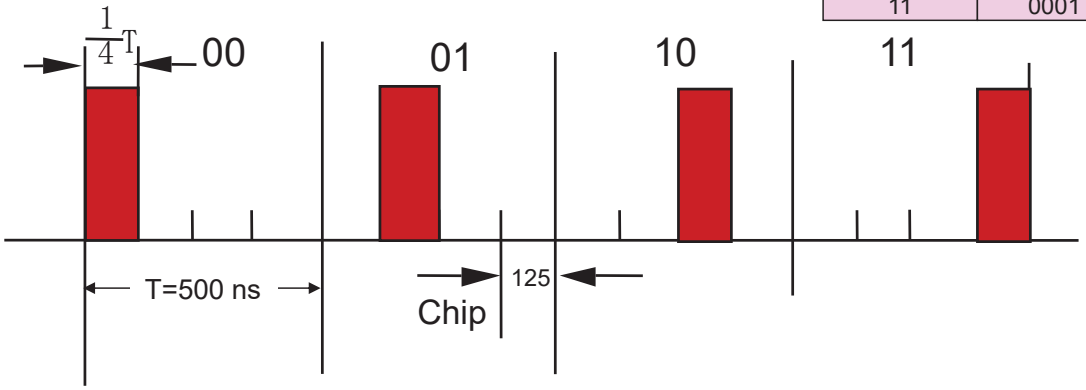
IrSimple (4value PPM, 4Mbps)

9.6 kbps - 1.152Mbps

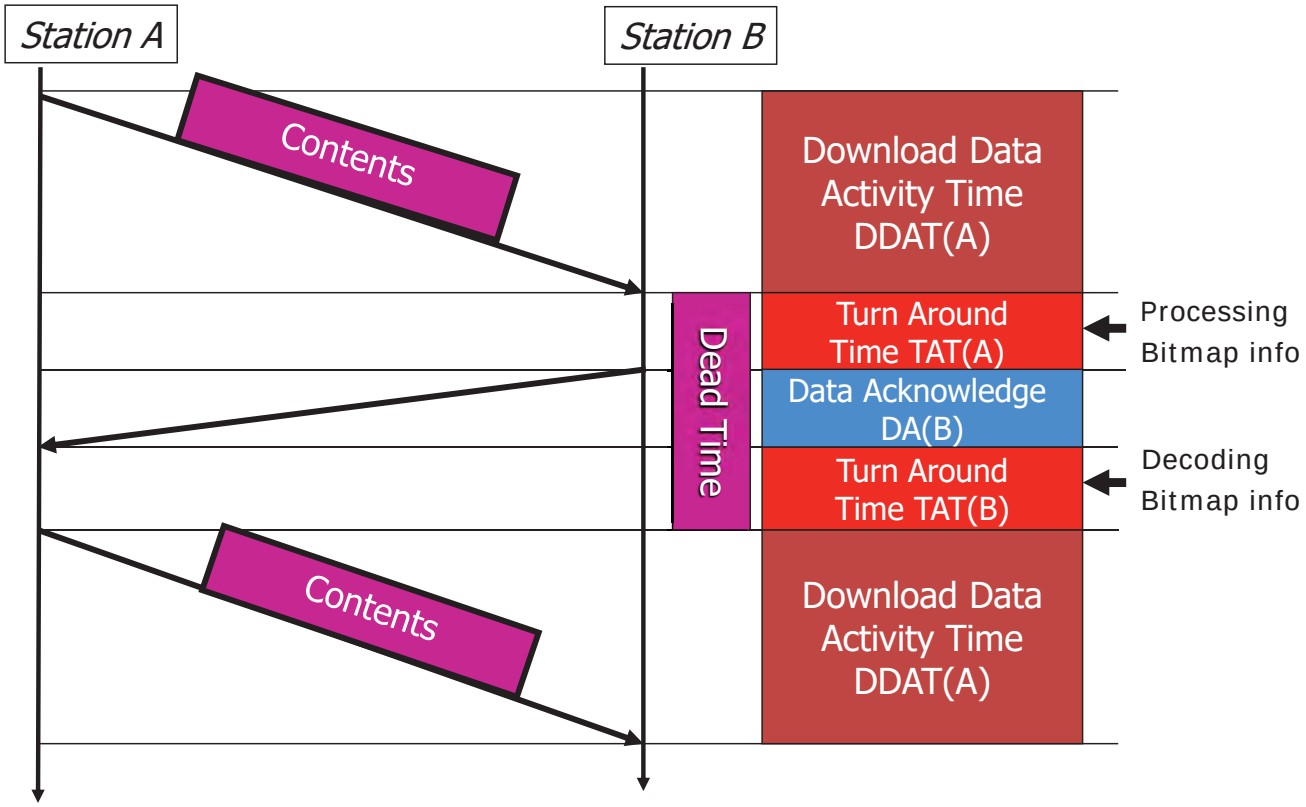


Data bit Pair (DBP)	4PPM Data Symbol(DD)
00	1000
01	0100
10	0010
11	0001

4Mbps(4-PPM)

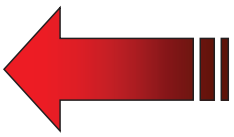


High efficiency technical challenges



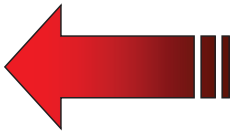
Comparison between early stage IrDA and IrSimple systems

Early stage system in case of 4Mbps



Approx. 6 sec

IrSimple system In case of 4Mbps



Approx. 1 sec

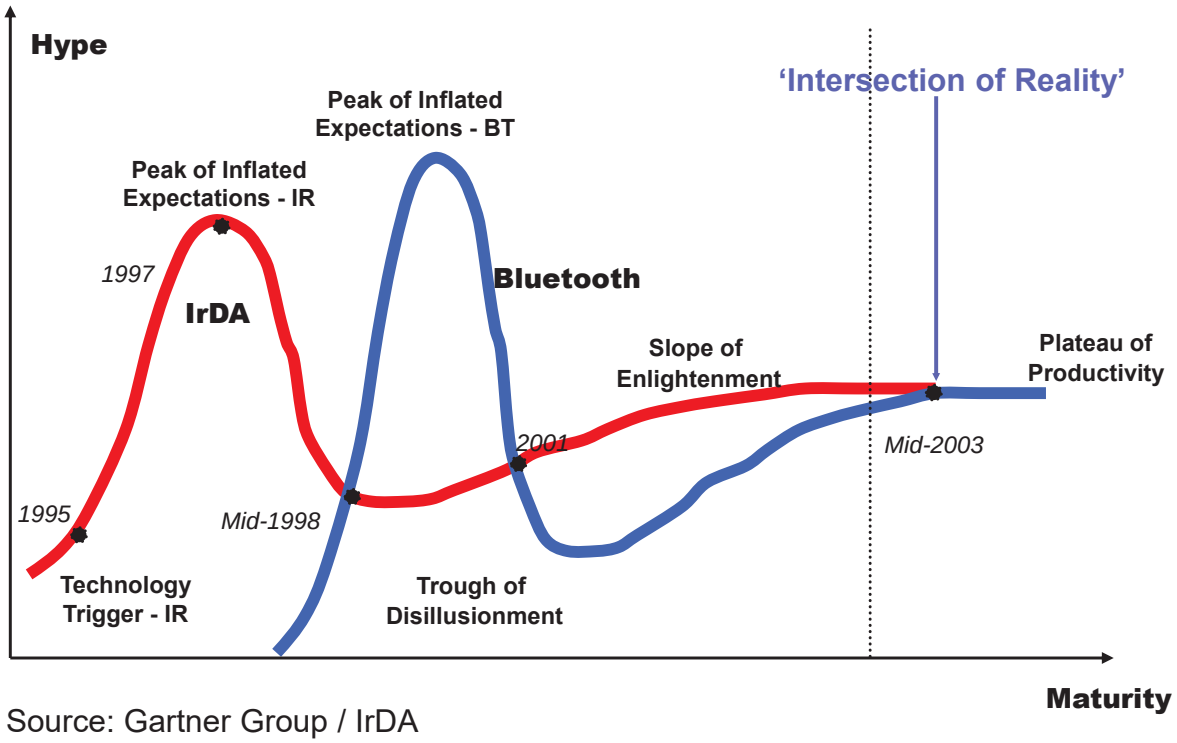
©500KB photo transfer

Connectivity utilization model

- Conscious connection
  - Point-to-Point Usage
    - Personal information transfer (vcard, vcal, etc…)
    - User initiated synchronization
    - Financial messaging
    - Walk-up printing
- Unconscious connection
  - Voice
  - Network Synchronization
  - Shared access device connectivity

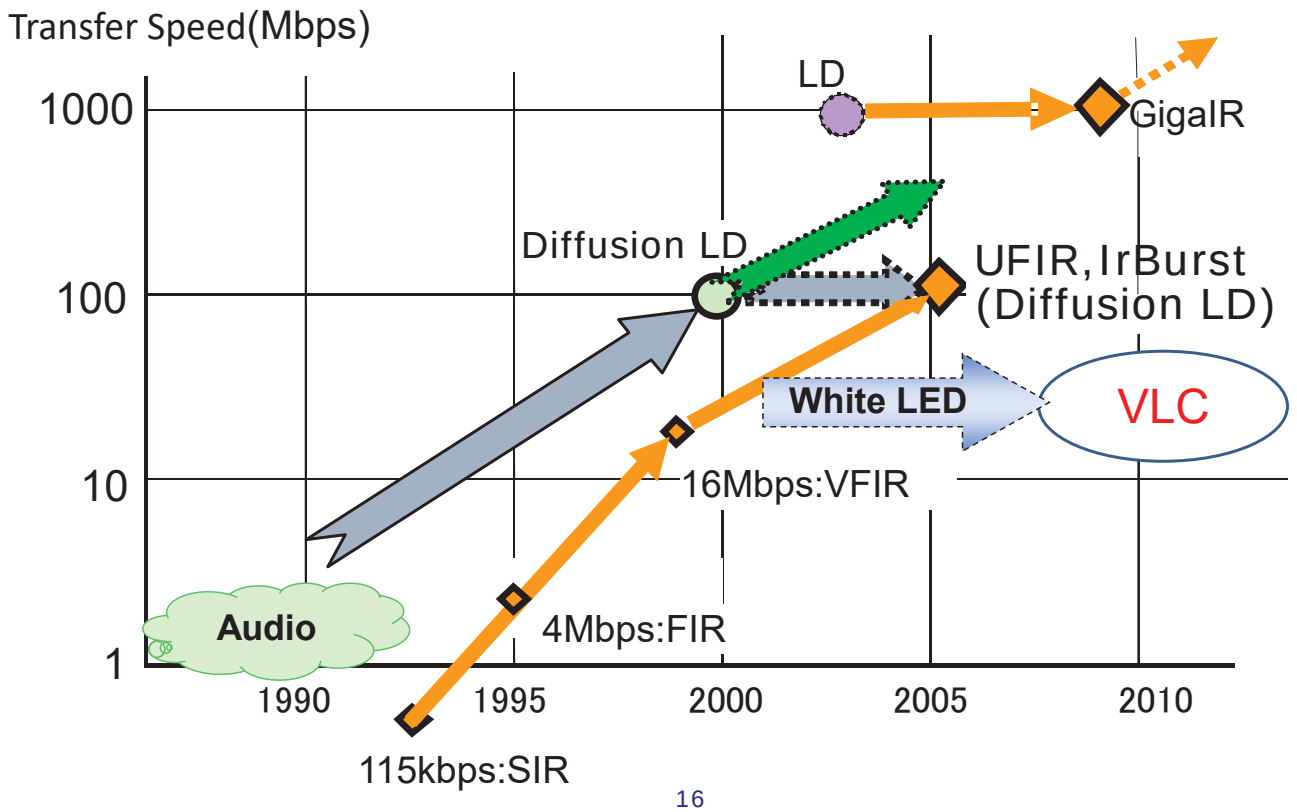
–Ericsson, Intel, IBM, Nokia, Toshiba (1800 companies)

Market conditions – maturity of IrDA and Bluetooth

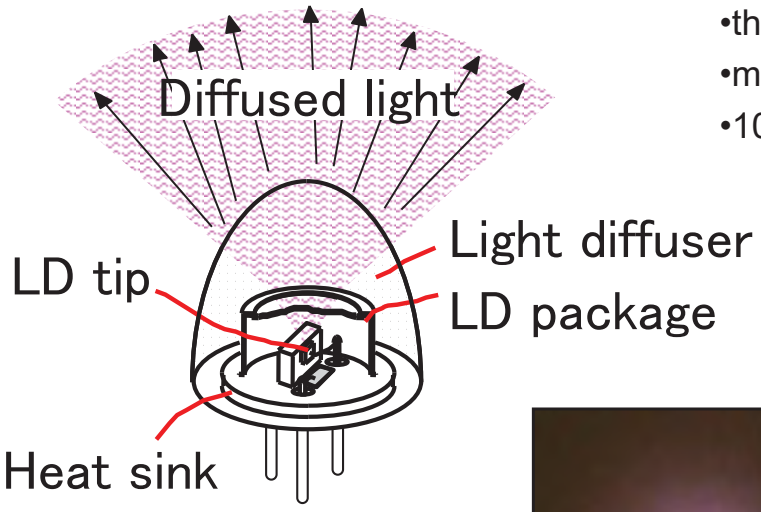


Source: Gartner Group / IrDA

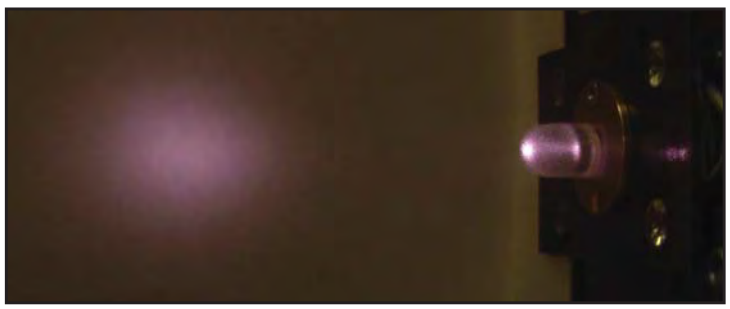
Product technology roadmap（IrDA)



Development of Eye Safe Laser Diode



- the spot size:1000 times
- measured beam diameter:4mm
- 100Mbps/1m



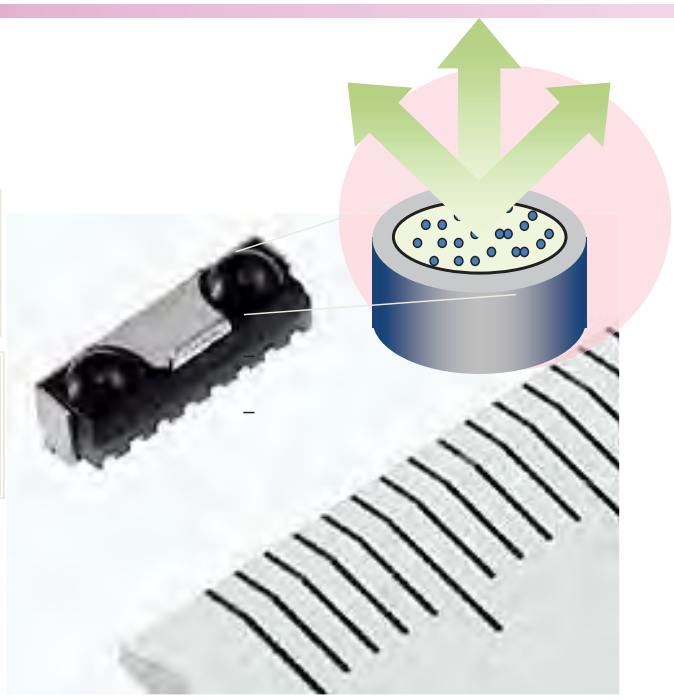
Same Approach is possible for miniature IrDA Unit

Source Size of >2mm will be possible with optimized lens

Operating Current is < 1/3 compared with LED

Modulation speed is >100MHz

100Mbps IrDA



Challenges of IR communication

- Speeding up of Light Emitting Element (LD, LED)
- Wide range Connectivity
  (Speed, Distance, Radiation angle)
- FDX(Full duplex transmission) and Throughput
- High Speed Transmission protocol
  (Short Confirmation, Turn Around Time)
- Interoperability (Standardization)
- Miniaturization (small size)
- Killer Application

Visible Light Communication (VLC)

- Visible Light communication is a wireless communication technology that uses light that is visible to humans

- Main features of VLC

(1) LED lights will be used everywhere

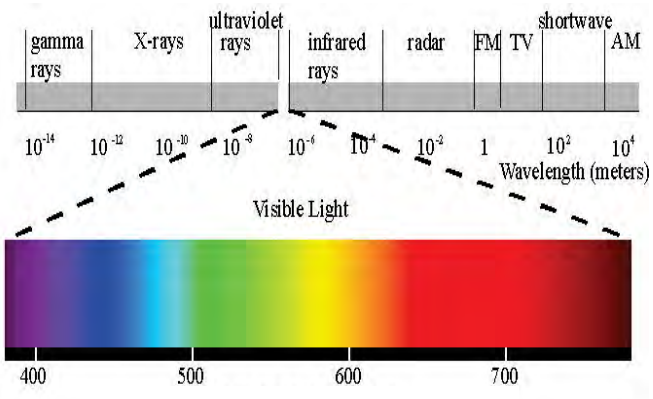
(2) Infrastructure is necessary for location services

(3) Easy identification of places or things

(4) There is no regulation for visible light communication so far

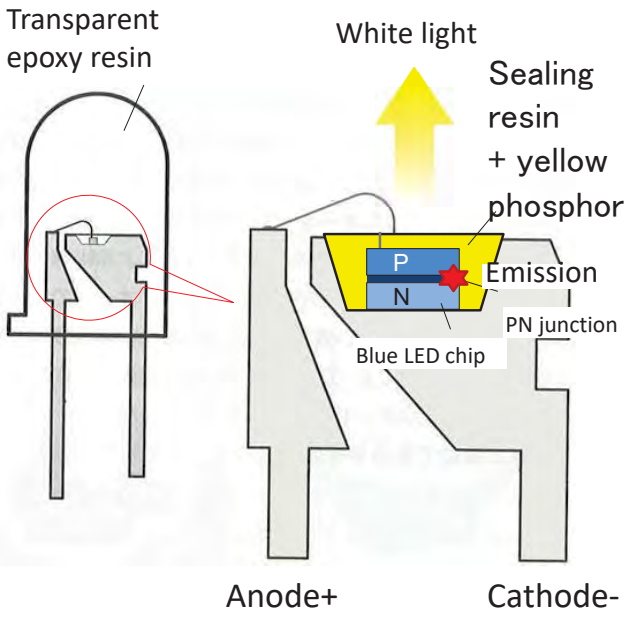
Visible Light Communication (VLC)

Definition :
Electromagnetic waves of wavelength 380-780 nm visible to human eyes.
When it comes into the human eye, it is recognized in the brain as color, each color has its own wavelength.

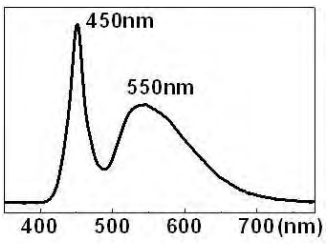


Visible light wavelength

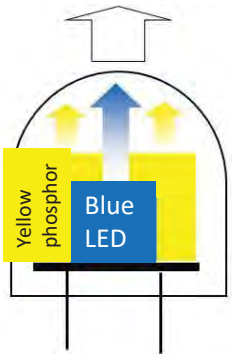
LED (semiconductor element emitting)



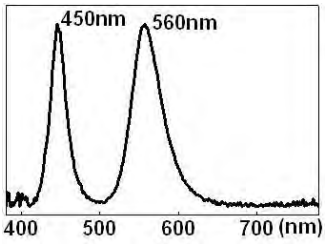
Light emitting method of white LED



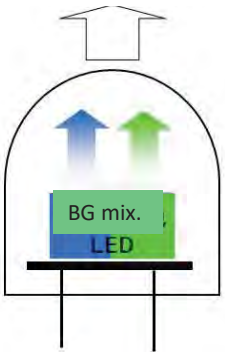
White light emission



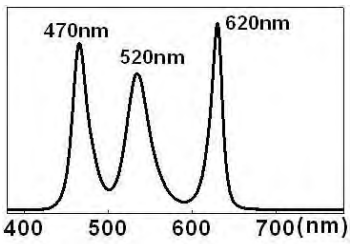
Blue LED+ Yellow phosphor
Complementary color



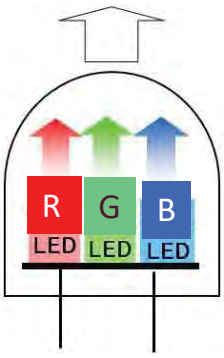
White light emission



White with one-chip LED with
blue/green color mixture

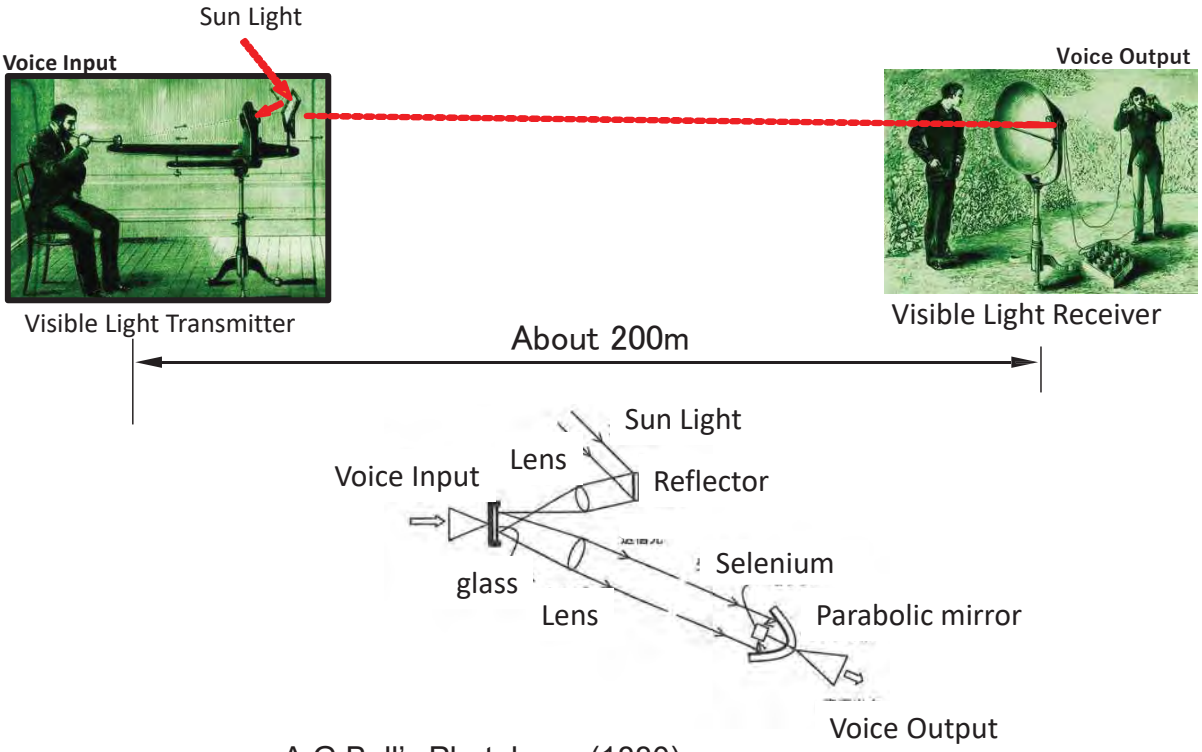


White light emission



White by combination of
red / green / blue LED

Origin of visible light wireless communication



A.G.Bell's Photohone (1880)

VLC characteristics

- Emits electromagnetic waves focusing on single wavelength with specific photons.
- Ease of directivity control
- Luminous efficiency 30 - 100 (lm / W)
- Regular light spectrum
- Fast response to current (short-time strobe lighting)
  ⇒Communication possible
- Light amplitude / intensity (light and dark)
- Optical wavelength (color)
- Optical phase (shape)

$$E_r = E_0 \cdot \cos 2\pi \left(\frac{r}{\lambda} - \frac{t}{T} \right)$$

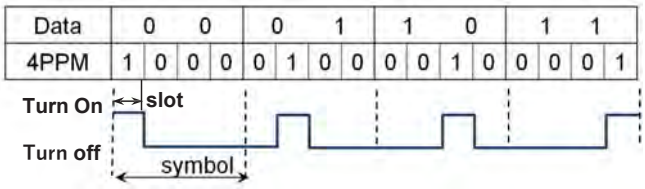
A modulation scheme effective for illumination optical communication

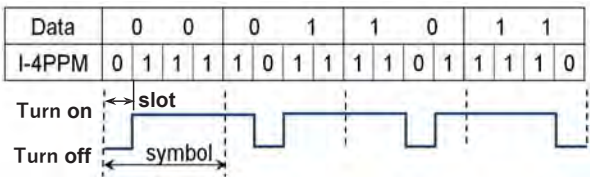
【Basic requirement】

- Maximize lighting characteristics
- Secure reception average power that can ensure desired SNR (BER)
- It is less susceptible to disturbance illumination light (fluorescent noise etc.)
- Even if any kind of data is modulated, a mechanism that always lights once

  -------- 4 PPM (Pulse Position Modulation)

[Modulation method]





Light receiving element for illumination optical communication

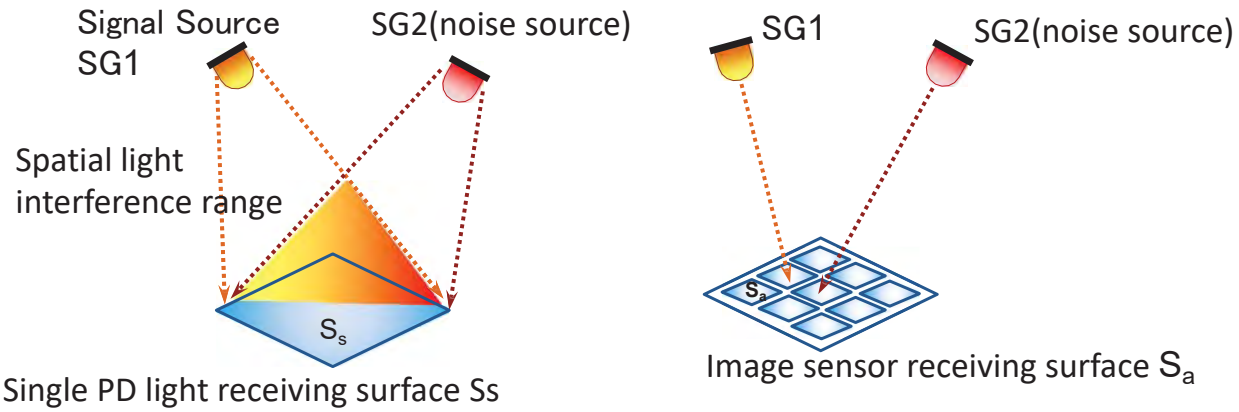
Basic requirement

- High sensitivity (receiving ability of weak optical signal)
- High-speed response (increase in code transmission speed)
- Low noise (SNR degradation of optical signal is small)
- High quantum efficiency (large number of carriers, increase in signal quantity) ;

Main light receiving element:

- Single PD/APD (APD: about 3-5 dB higher sensitivity than PD)
- Two-dimensional image sensor (array of PD / APD)

Comparison of light receiving methods of single and two-dimensional elements



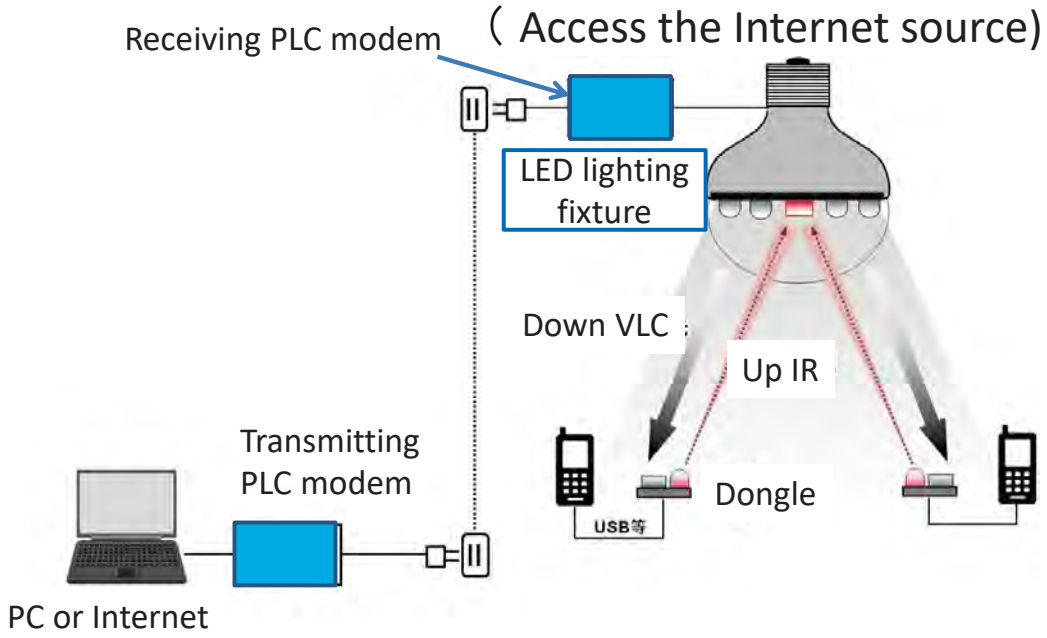
Single PD light receiving surface Ss

Image sensor receiving surface S_a

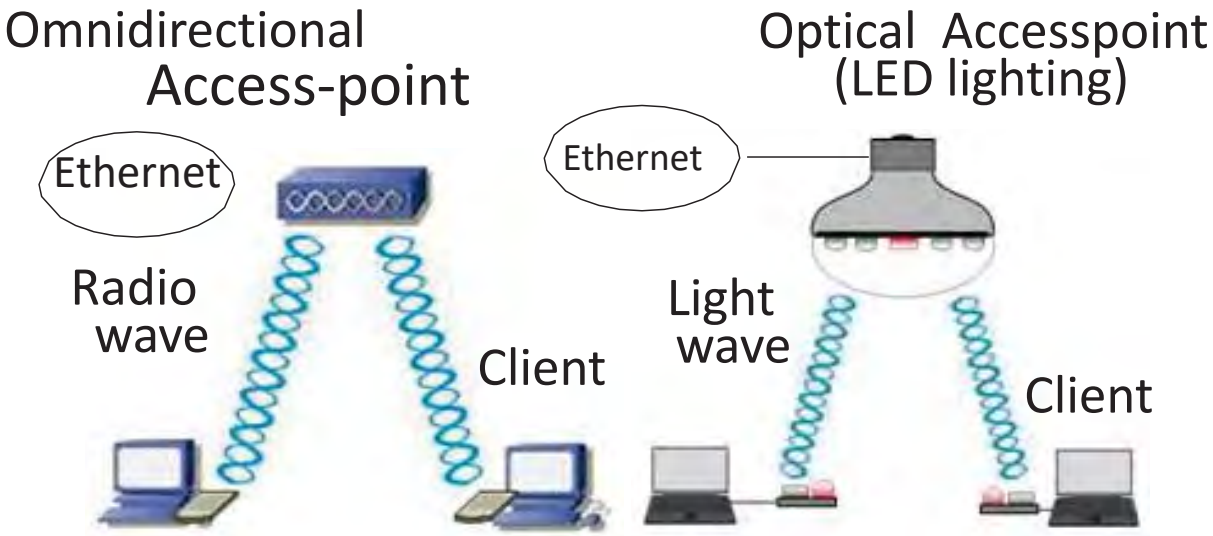
- Easy structure, high speed operation by element;
- It is weak against influence of background light noise due to surface light reception, making it difficult to communicate over long distances.

- Point light reception is strong against the influence of background light noise and communication at long distance is possible;
- Since the multiple signals are processed simultaneously, the load is greatly high
  Fast communication is difficult;
- Flicker occurs at low speed (frame rate is several tens of kHz).

Optical Wireless LAN
(Omnidirectional system structure)



Wi-Fi and Li-Fi



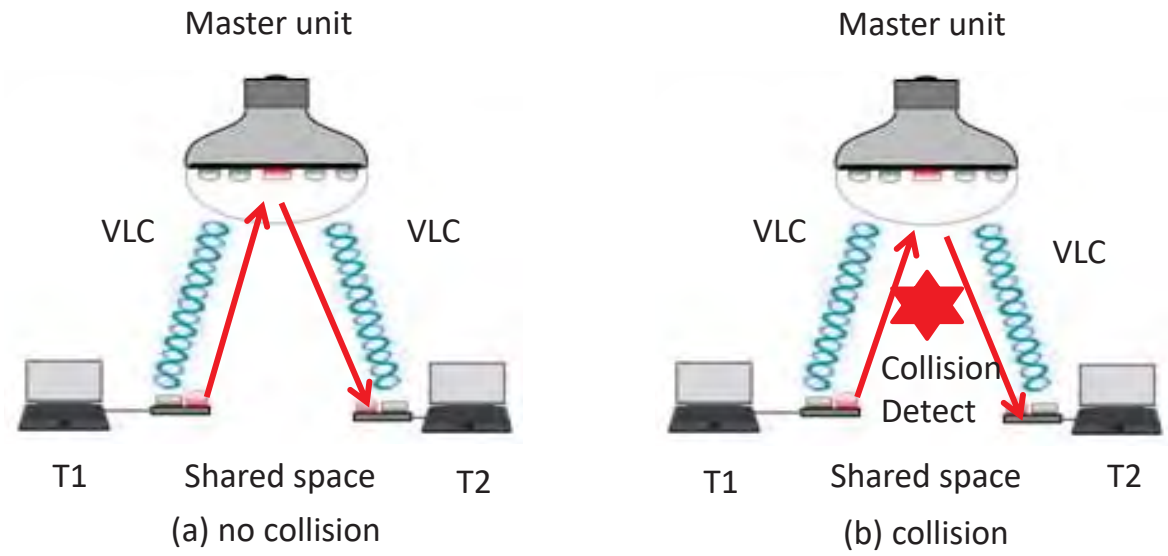
Wireless LAN card

(a) Wi-Fi

Optical wireless dongle

(b) Li-Fi

Challenges



Principle of spatial light CSMA / CD (CA):

IEEE 802.3 CSMA/CD (CA): carrier sense multiple access with collision detection/avoidance

Under water communication

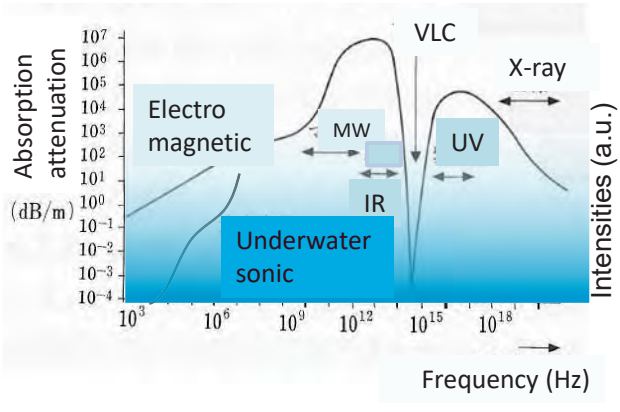
Photos provided by Toyo Electric.

Comparison of underwater data radio propagation method

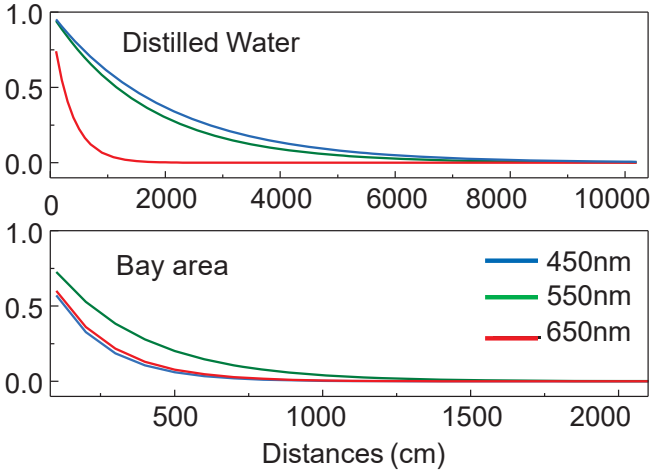
	Radio wave	sound waves	light waves
Distance	Long range transmission possible with low frequency	Compared to light and radio waves, attenuation is small and it can be transmitted far away	Damping due to absorption / scattering / light shielding, short distance (average about 15 - 100 m)
speed	There is a speed limit. Faster than in air (average about 1500 m / s)	Speed depends on water pressure and water temperature	Sound velocity minimum around 1000 m (approx. 1470 m / s)
capacity	The amount of information that can be transmitted with as low frequency as possible is small		Large capacity (easy to control due to visibility)

For seawater and freshwater, fresh water has longer propagation distance at any frequency

Frequency Characteristic in under sea



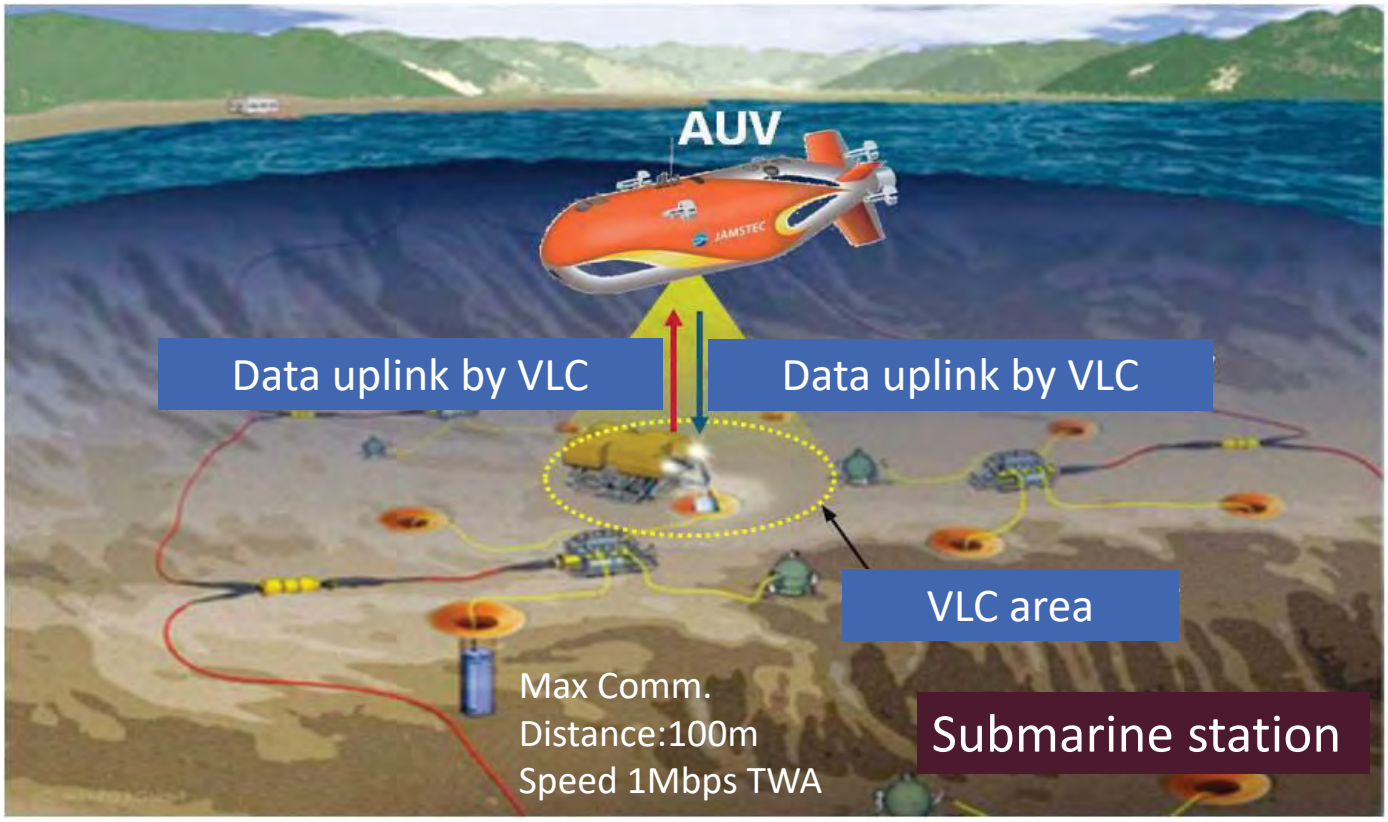
Attenuation of electromagnetic waves (Radio wave/Light) and sound waves in seawater



Spectral decay of transmission distance by extinction coefficient

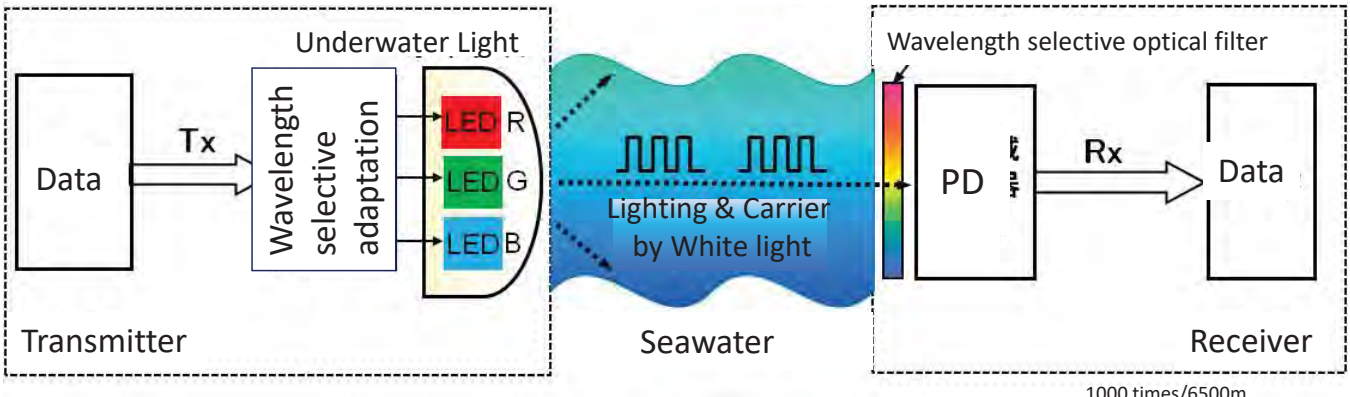
F/Fo＝e-cL
C(Extinction co.) ＝a(Absorption co.)＋b(Scattering co.)
Fo(Incident parallel light flux)

Ocean environment VLC system (Submarine exploration) by JAMSTEC



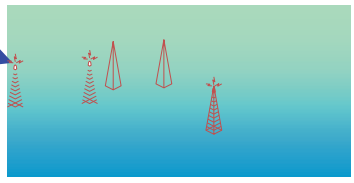
Marine environment visible light wireless communication system

VLC data transfer between AUV (autonomous underwater vehicle) and Under Sea Station



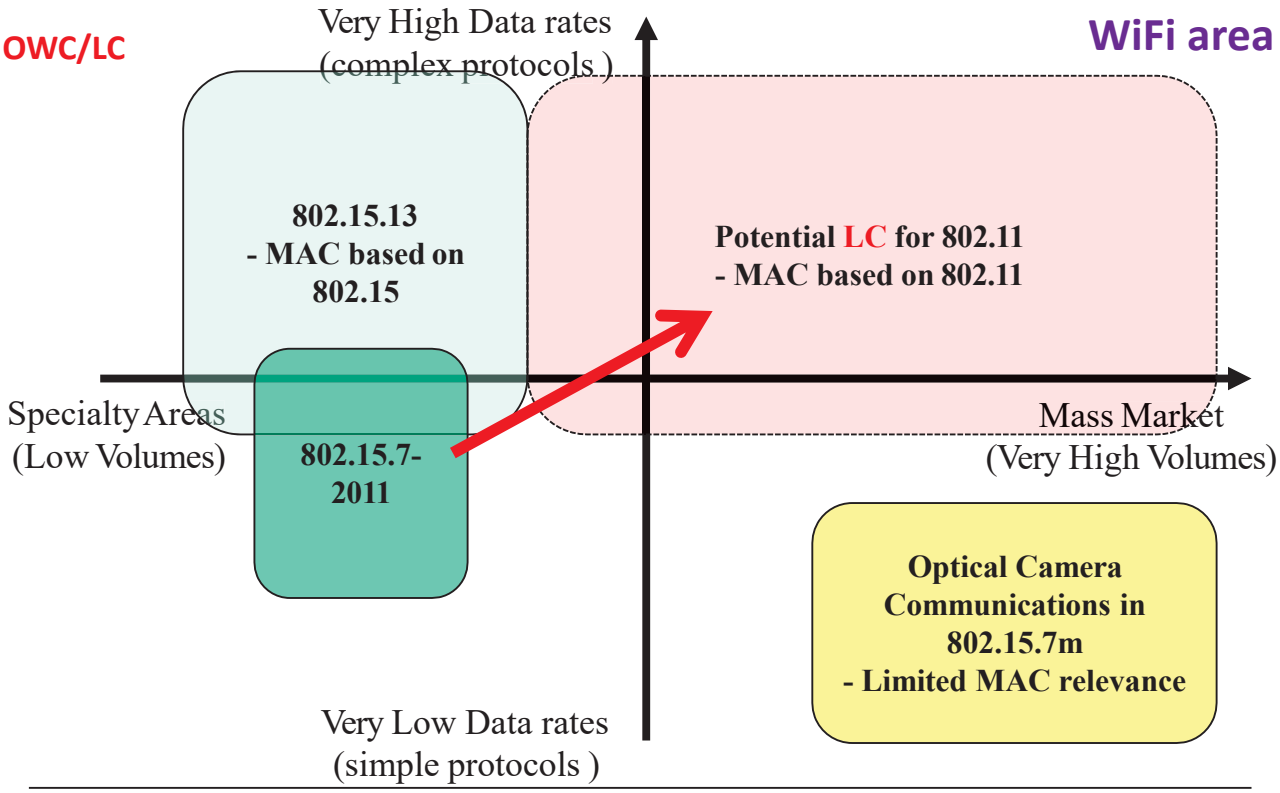
1200 times/
6500m/
3 person

Adaptive measures for marine environment



"Shinkai 6500" is a submersible survey ship capable of dive to 6,500 m in depth (1989) -JAMSTEC

The IEEE 802 OWC standards



IEEE 802.11 can bring high-speed LC to the mass market faster and in a more comprehensive manner other SDO

ITU-T Study Group G.vlc

- Based on G.hn – Home Networking standard
- Customer Premises Equipment may use G.hn

802.15.7r1

- Originally based on 802.15.4 - Not designed for networking, e.g., No 48 bit MAC address, different security,…

802.15.13

- Based on 802.15.7r1 with focus on Muli- Gigabit/s Optical Wireless Communications suitable for speciality wireless networks

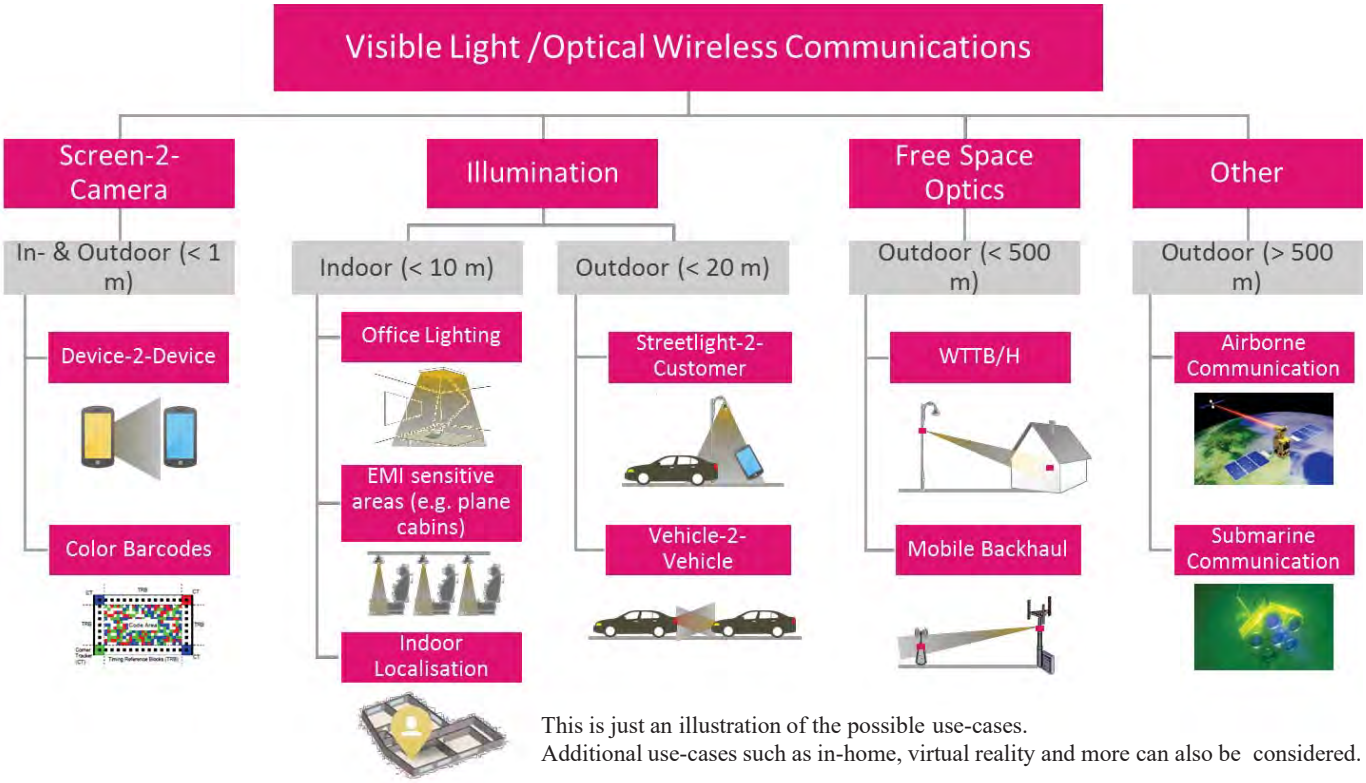
Problem

Neither effort has the comprehensive ecosystem of partners required for mass market adoption of LC.

Proposed – 802.11 has unique ecosystem

- Chipset vendors, Network Infrastructure, Device Integrators,
- End Customer and Operators

LC can address a number of different use-cases



This is just an illustration of the possible use-cases.
Additional use-cases such as in-home, virtual reality and more can also be considered.

FSO Application scenarios

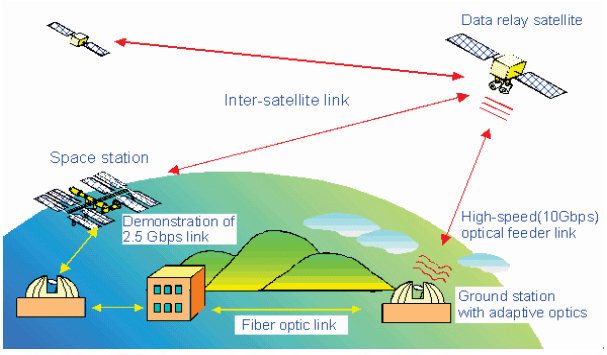
Depending on the deployment scenario and application, the FSO communication system is suitable for terrestrial, ocean and space based communication.

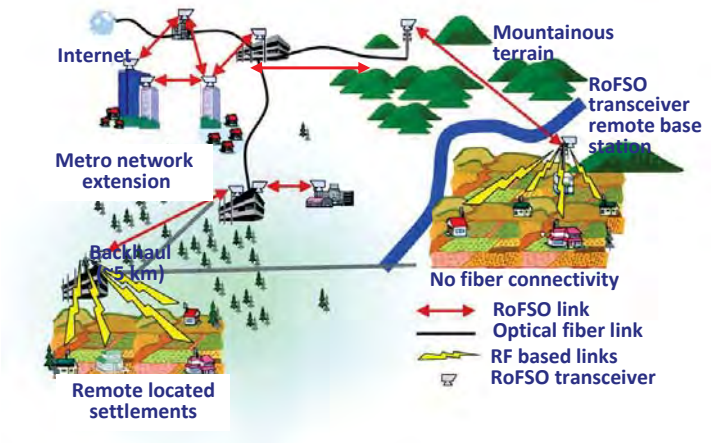
For space-based communication,

- Deep space communication
- Inter-satellite communication
- Satellite to Ground communication
- Manned spacecraft]

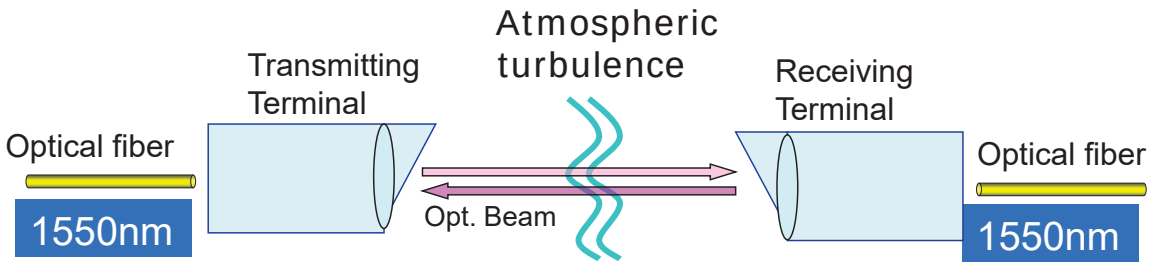
In the case of terrestrial communication,

- Metro network extension
- Last mile access
- Enterprise connectivity
- Remote located settlements
- Fiber backup
- Temporary line in case of disaster, etc.



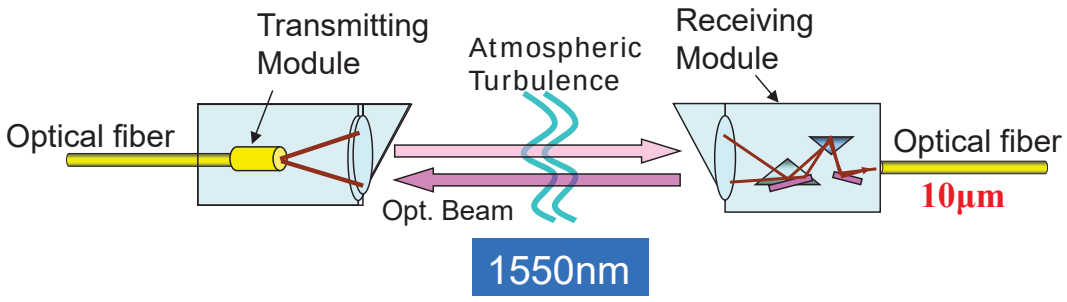


What are the challenges of FSO?



- How to realize Ultra High Speed and Reliable Optical Link through the atmosphere, based on the compatibility with existing fiber infrastructure using 1550 nm wavelength

Direct coupling high-speed FSO system



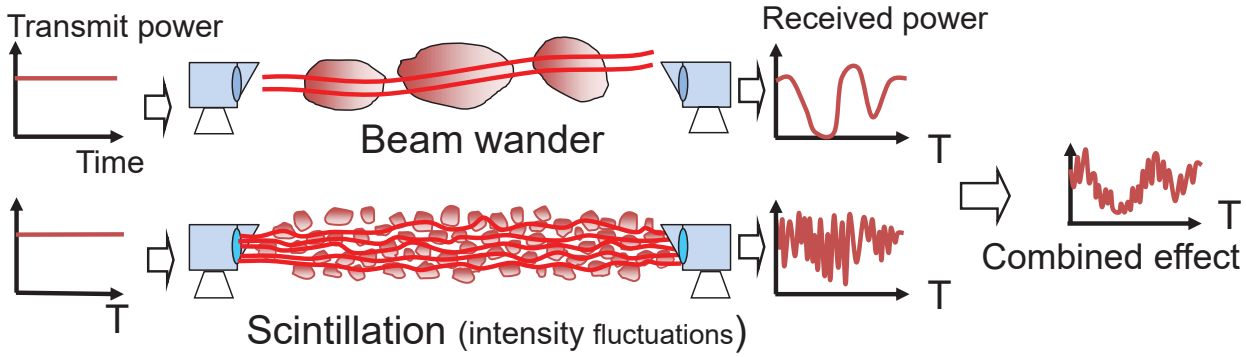
By Direct coupling between optical fiber and free-space

- No O/E & E/O conversion
- Uses 1550nm wavelength
- Compatibility with existing fiber infrastructure.
- Protocol and data rate independent. Seamless connection of space and optical fiber.
- broad bandwidth (InGaAs) and no power limitations
- Tracking control mechanism
- Provide high speed physical transmission path and services equivalent to optical fiber.

Influence of atmosphere on FSO

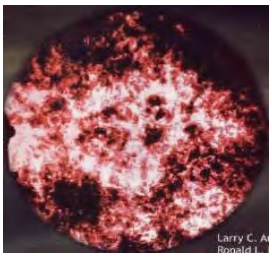
- Because transmission environment of FSO is the atmosphere, so there are many influences on the system performance, including attenuation due to rain, fog, snow and especially turbulence due to the variation of temperature and pressure, etc.
- Among them, effects of fog and turbulence are severe. However, in the case of fog, we can overcome by some way for example increase transmission power or pre-amplifier gain.
- For many cases of practical problem, optical turbulence is the limiting factor in reliable free-space optical communication link performance. In particular, the problem in guiding the light beam to the SMF is that the fluctuation of the atmospheric fluctuation : Scintillation

Problem when guiding the light beam to the SMF

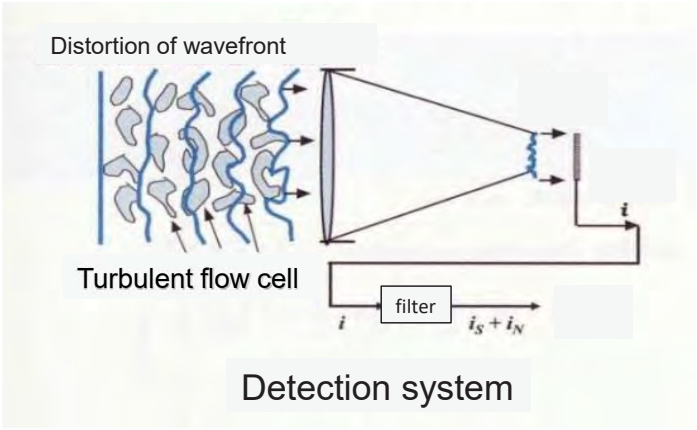


- In general, atmospheric fluctuations are refracted and change the direction of travel when passing through the boundary of air masses with slightly different densities. (ex. heat haze or blinking of stars).
- Beam wander: a phenomenon when the direction of optical beam changes when relatively macroscopic air mass is passed. Daily, Seasonal variation.
- Scintillation or intensity fluctuation : a phenomenon that the received power fluctuates at short cycles (1-10ms) when the light beam propagates in the atmosphere. (the particle diameter is smaller than the beam diameter and it becomes active when the temperature is high and the humidity is high)

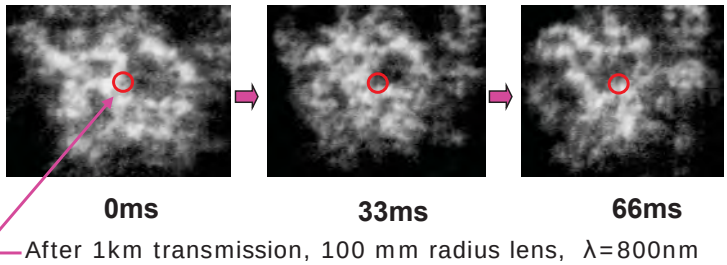
Scintillation

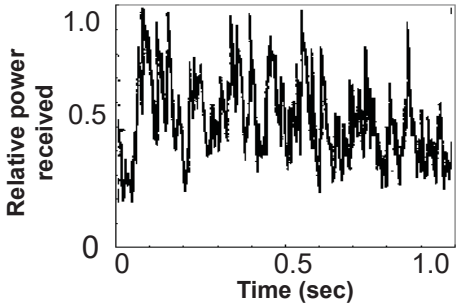


Andrews Larry.C., Phillips R.L., Cynthia Y. Hopen; "Laser Beam Scintillation With Applications"

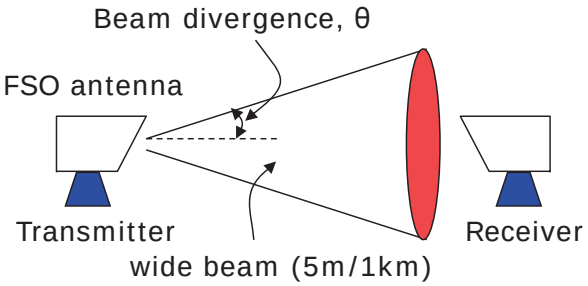


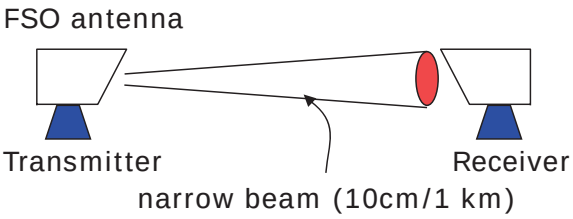
Ex:Change of beam pattern by scintillation

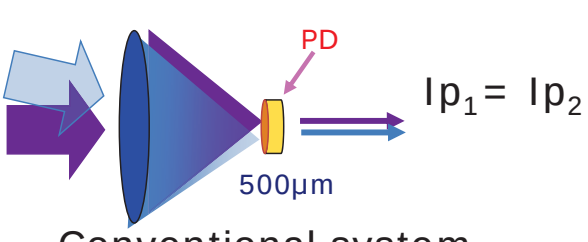




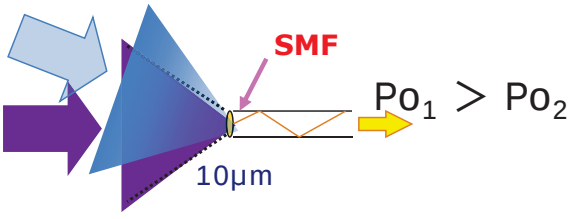
Sensing Mechanism







Conventional system



Direct coupling FSO system

- To mitigate atmospheric effects **Tracking system is required**

PD: Photodiode (Si, InGaAs; SMF: Single Mode Fiber

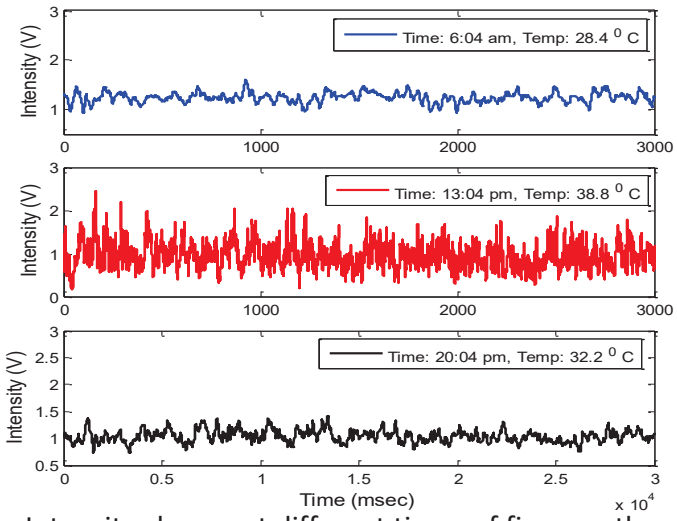
Evaluation of atmospheric turbulence

- C_n^2 is refractive index structure constant, used to indicate atmospheric turbulence strength
- σ_I^2 : scintillation index (Normalized intensity variance)
- Weak : $10^{-15} \le C_n^2 < 10^{-14}$
- moderate: $10^{-14} \le C_n^2 \le 5 \times 10^{-14}$
- strong: $5 \times 10^{-14} \le C_n^2$

$$\sigma_I^2 = \frac{\left\langle [I - \langle I \rangle]^2 \right\rangle}{\langle I \rangle^2} \qquad \sigma_I^2 = 1.23 C_n^2 k^{7/6} L^{11/6}$$

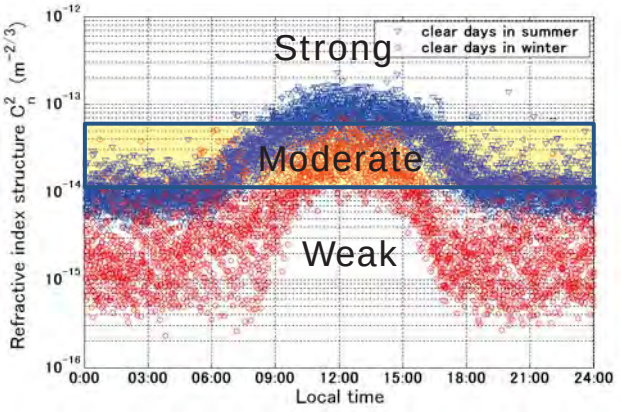
(Rytov variance)

$$C_n^2 = \frac{\left\langle [I - \langle I \rangle]^2 \right\rangle}{\langle I \rangle^2} / (1.23 \times (2\pi/\lambda)^{7/6} \times L^{11/6} \times [1 + 1.06 \times D^2 2\pi/(\lambda \times 4l)]^{-7/6})$$



Intensity change at different times of fine weather

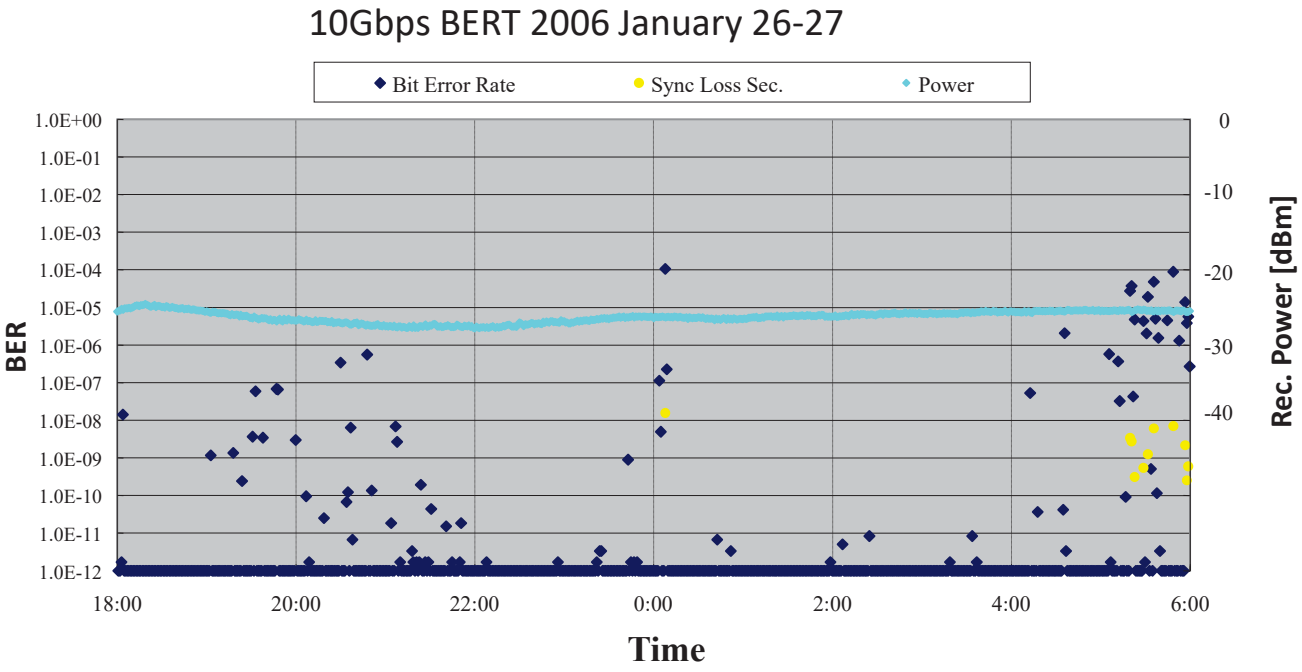
C_n^2 in in summer and winter



Strong: at noon of fine day

Weak: sunrise, sunset, rainy days

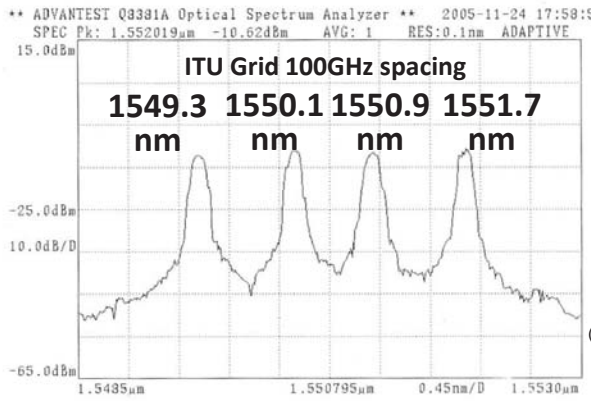
10Gbps Transmission



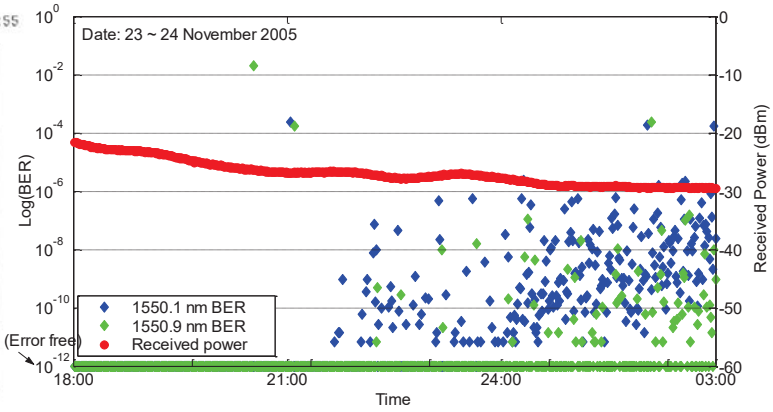
WDM Experiment setup and results

Four channel 1550 nm data link operating at 2.5 Gbps WDM

WDM received signal spectrum



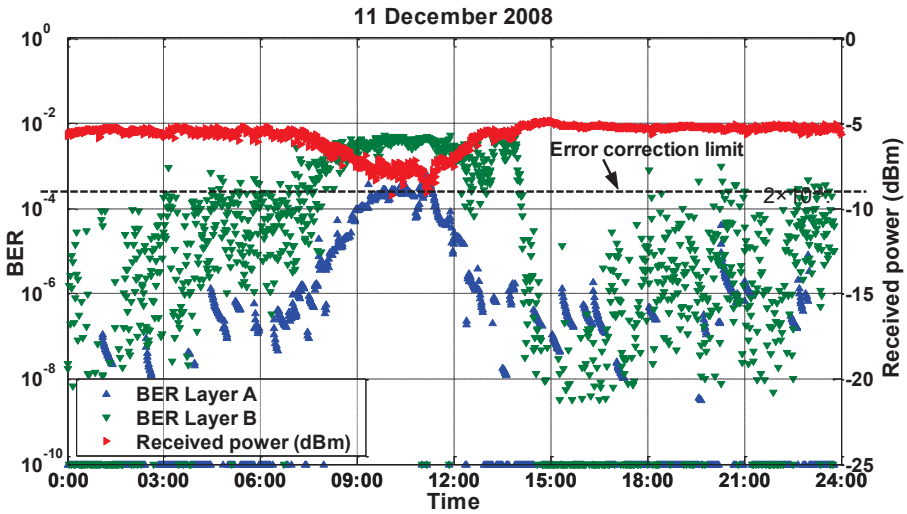
BER and received power characteristics



- 2.5 Gbps X 4 channels with output power 100mW/wavelength
- Stable communication was achieved with no fluctuation or interference between wavelengths (an output power of 100 mW per wavelength)

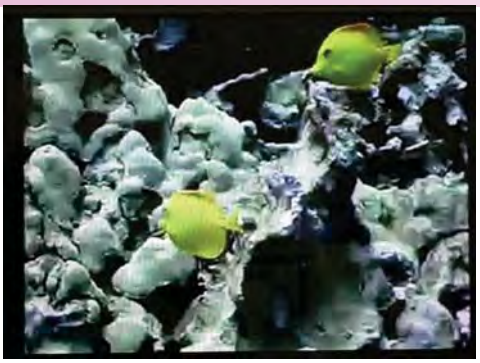
RoFSO Movie image transmission result

Digital TV broadcasting signal transmission



Digital TV broadcasting BER and received optical power characteristics.

BER shown here is calculated from error correction information. The error rate currently displayed is between for an error correction with a RS and Viterbi cord. Error collection limit is 2×10^{-4}.

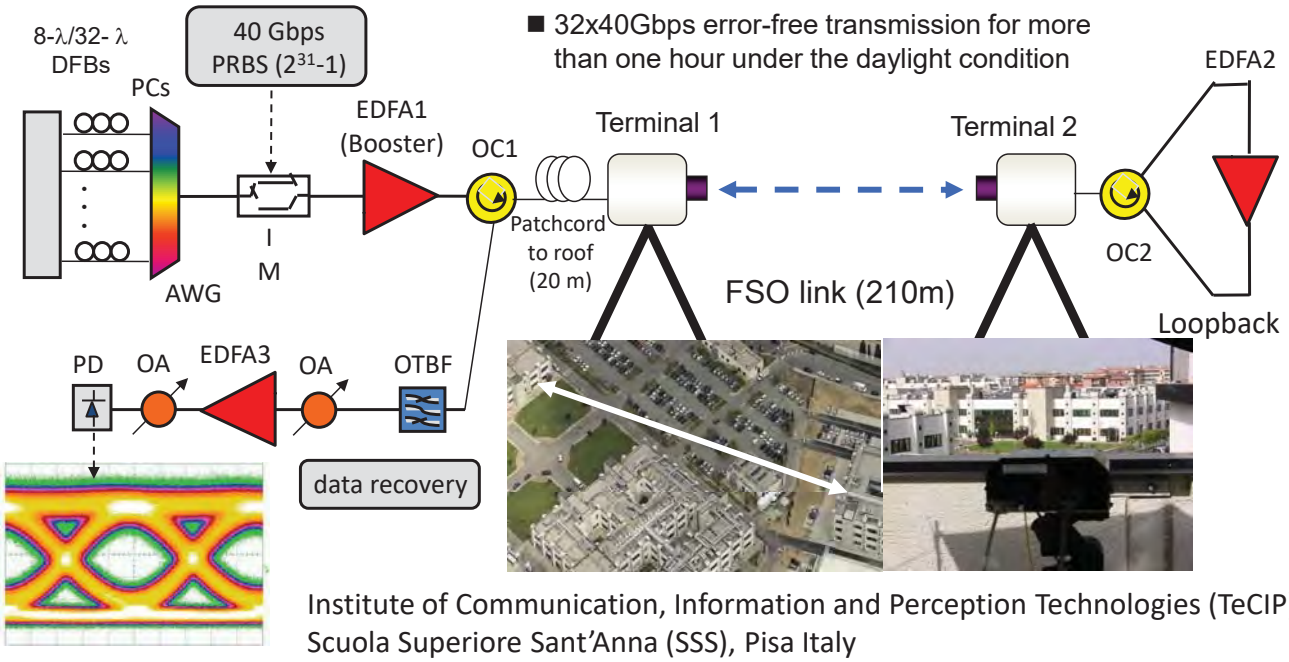


A-Layer 1seg video

B-Layer 12-segment video

Ultra High Speed FSO Transmission Experiment

1.28Tbit/s Transmission CNR Pisa, Italy 5th Sept.2008

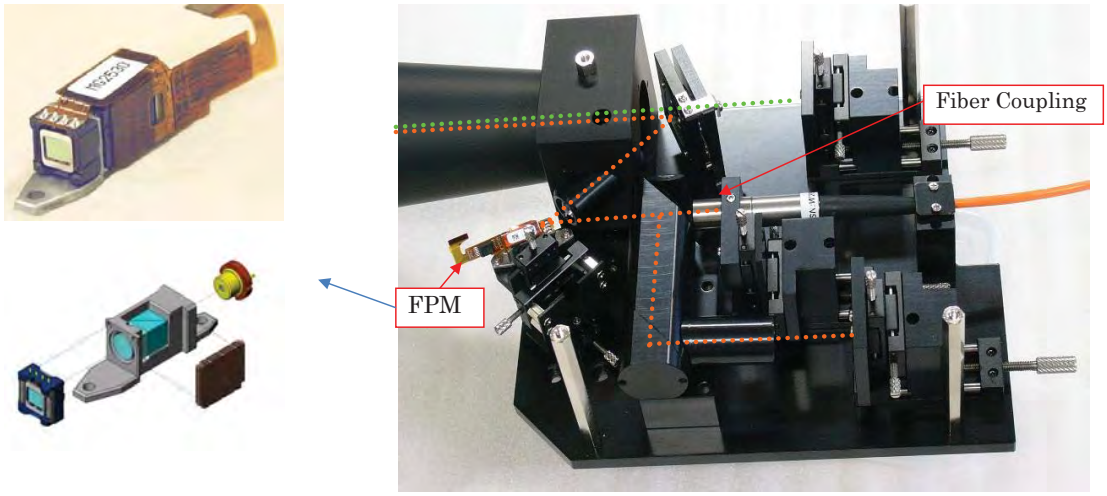


Institute of Communication, Information and Perception Technologies (TeCIP), Scuola Superiore Sant'Anna (SSS), Pisa Italy

Achieved 1.28 Tera bits per second world record transmission for a wireless system using a system based a similar concept.
E. Ciaramella, Y. Arimoto, G.Contestable, M. Presi, A. D' Errico, V. Guanno, and M. Matsumoto, " 1.28 Terabit/s (32x40 Gbit/s) WDM Transmission System for Free Space Optical Communications," IEEE Journal Areas in Com. vol. 27, no. 9, Dec. 2009.

Mitigation techniques by present system

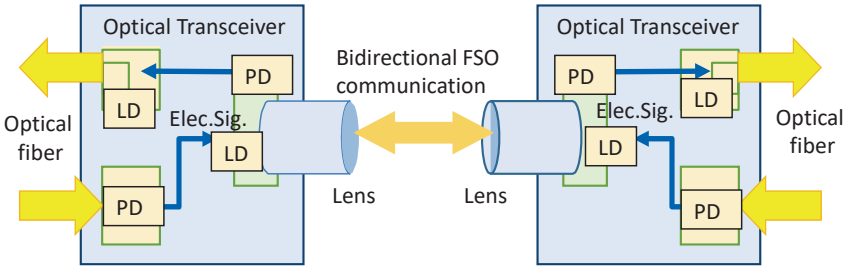
- We adopted adaptive optics to compensate the influence of light propagating in the atmosphere in real time. In particular, we adopted an optical axis control method using ultra-compact, biaxial, galvano mirror with fast response.
- The internal angle control is performed by monitoring the deflection angle by two-dimensional driving, and it operates stably up to 2 kHz in both azimuth (Az) and elevation (El) directions.



FSO Tracking system Evolution

1. Conventional System

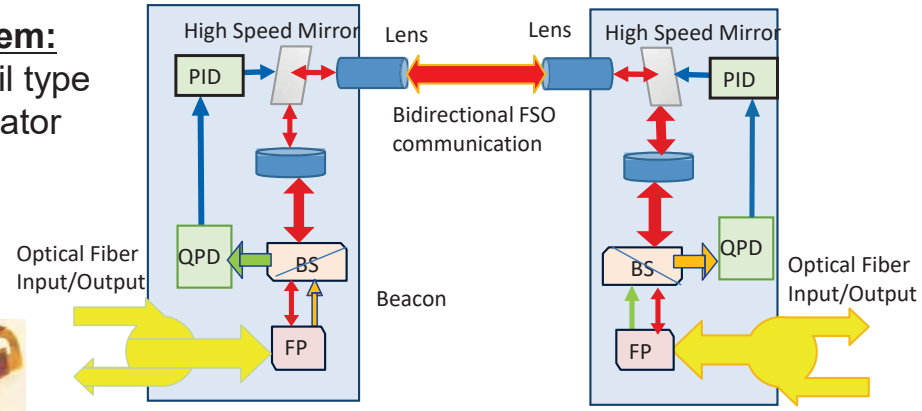
- O/E/O conversion
- Received by Large PD
- Rough tracking by beacon signal



2. New developed system:

Ultra-compact moving coil type galvanometer mirror actuator

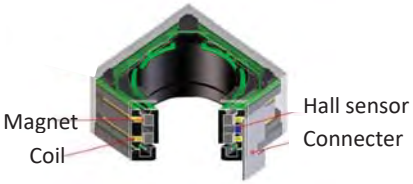
- No O/E/E conversion
- Received by Fiber core
- Rough tracking by beacon signal

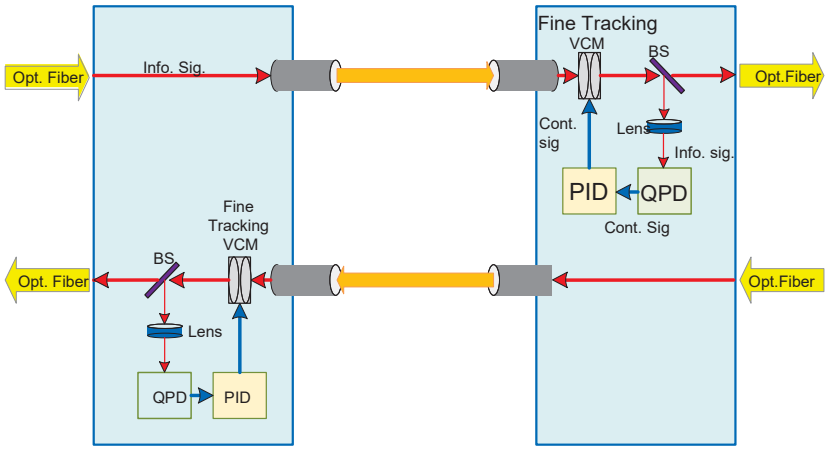


FSO Terminal Evolution-2

3. Future system using closed loop voice coil actuator

VCM having the function of converting electric energy into kinetic energy with a magnetic field as a medium





1. Development of eye-safe laser region Light wavelength: 1550 nm (1 wavelength)
   · Beacon light: 800-900nm unnecessary
2. Reduction in tracking servo technology, reduction in size, improvement in accuracy
   · Sensor: GPS, direction sensor, gyro
   · Control: VCM

Conclusion in FSO

1) We developed an FSO system which uses **narrow beam transmission** with **direct coupling to the SMF fiber core** and **without performing O/E and E/O conversion,** which make the communication link bandwidth and protocol transparent. Using technologies such **as WDM and EDFA**, high data rate in the order **of several Gbps was demonstrated**.
2) Evaluating the received optical power level and the propagation link quality for a continuous period of more than one year, the operating data rate **exceeding 1.5 Gbps was demonstrated at a distance of 1-km with the link availability above 99.9%.**
3) In the absence of severe weather conditions such as atmospheric turbulence, heavy rain, thick fog, snow and storm, the ISDB-T and W-CDMA signals were transmitted using the FSO system and good performance was achieved.
4) The obtained results confirm the technical feasibility and practicality of utilizing the FSO system **as a universal platform for providing 5G wireless services.**

Further Study

1) Development of a high-speed communication system between satellite stations, satellites, aircraft, railroads, ships and ground stations.
2) **Realize a simple, inexpensive, robust FSO system and aim to spread FSO**.
3) Consideration of standardization accompanying increase of multiple standards.
4) Further experiments are needed to gather data for statistical analysis of system performance under different weather conditions.
5) Building Initial Setting Free, Eye safe

OVERVIEW FOR OPTICAL WIRELESS COMMUNICATION

Thank you for your attention