Visible Light Communication (VLC) and its Applications

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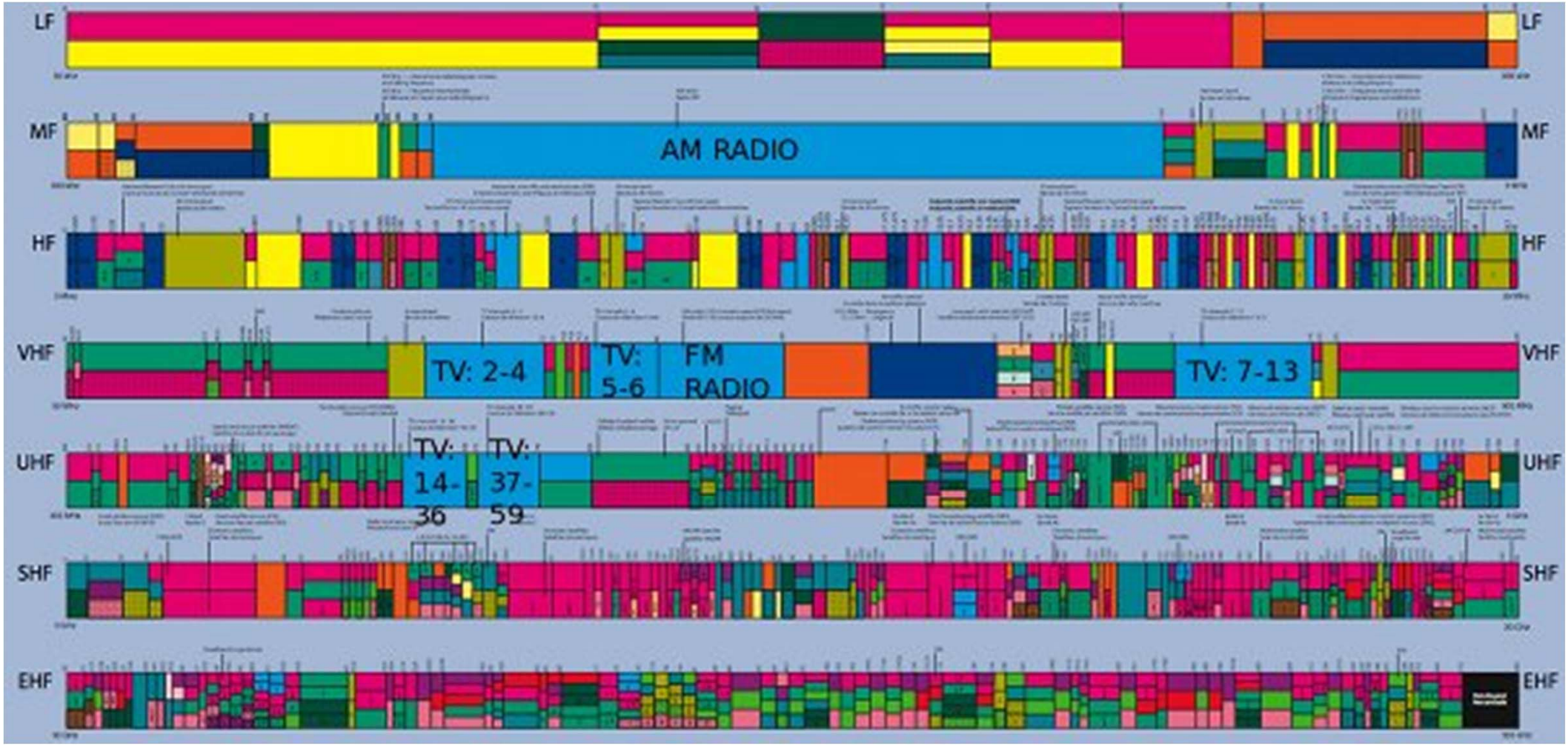
โครงการพัฒนาความพร้อมระดับประเทศของการสื่อสารด้วยแสงสว่าง:
การถ่ายทอดเทคโนโลยี การพัฒนาบุคลากรด้านกิจการโทรคมนาคม การจัดทำร่างมาตรฐาน และสื่อ

Outline

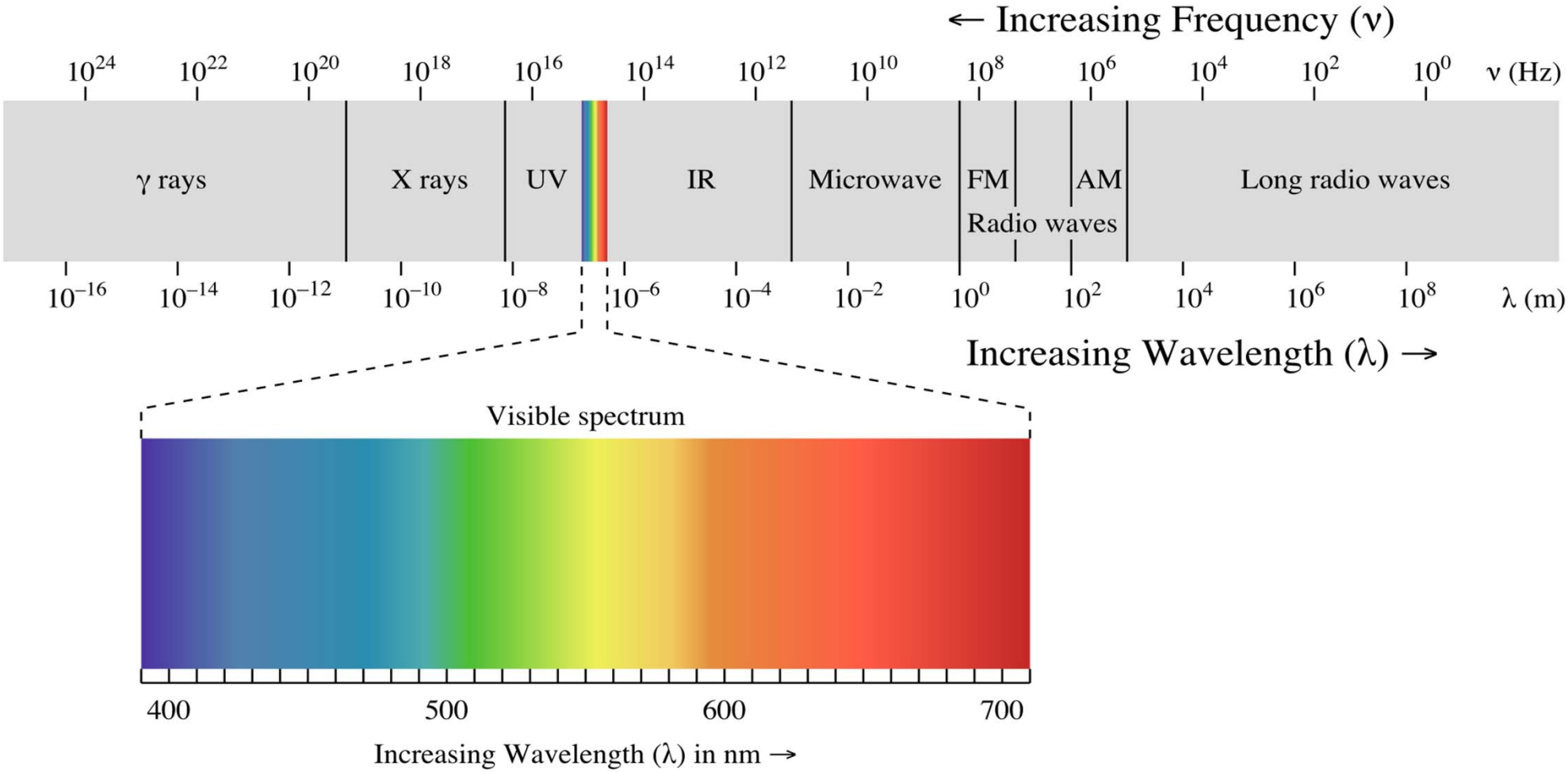
- Optical Wireless Background
- Introduction
- History
- Motivation
- VLC System
- Light Source
- VLC Applications
- VLC Demonstration

Why Optical Wireless (OW)?



- RF spectrum: crowded / expensive
- **OW spectrum: free / large bandwidth**

Frequency band for VLC



“ ที่ใดมีแสงแอลอีดี ที่นั้นมีข้อมูลข่าวสาร ”

Definition

- Visible light communication (VLC) refers to the communication technology, which utilizes the visible light source as a signal transmitter, the air as a transmission medium, and the appropriate photodiode as a signal receiving component.

- Visible light is the form in which electromagnetic radiation with wavelengths in a particular range is interpreted by the human brain.
  - Visible light is comprised of visually-perceivable electromagnetic waves.
  - The visible spectrum covers wave lengths from 380 nm to 750 nm.

OW Application (short range)

- Traffic communication
- Public data broadcasting
- Indoor broadband broadcasting
  - Hospital / Supermarket / University / Office
- Home access networks
- Military communication

Home/Office Wireless Network

- WiFi

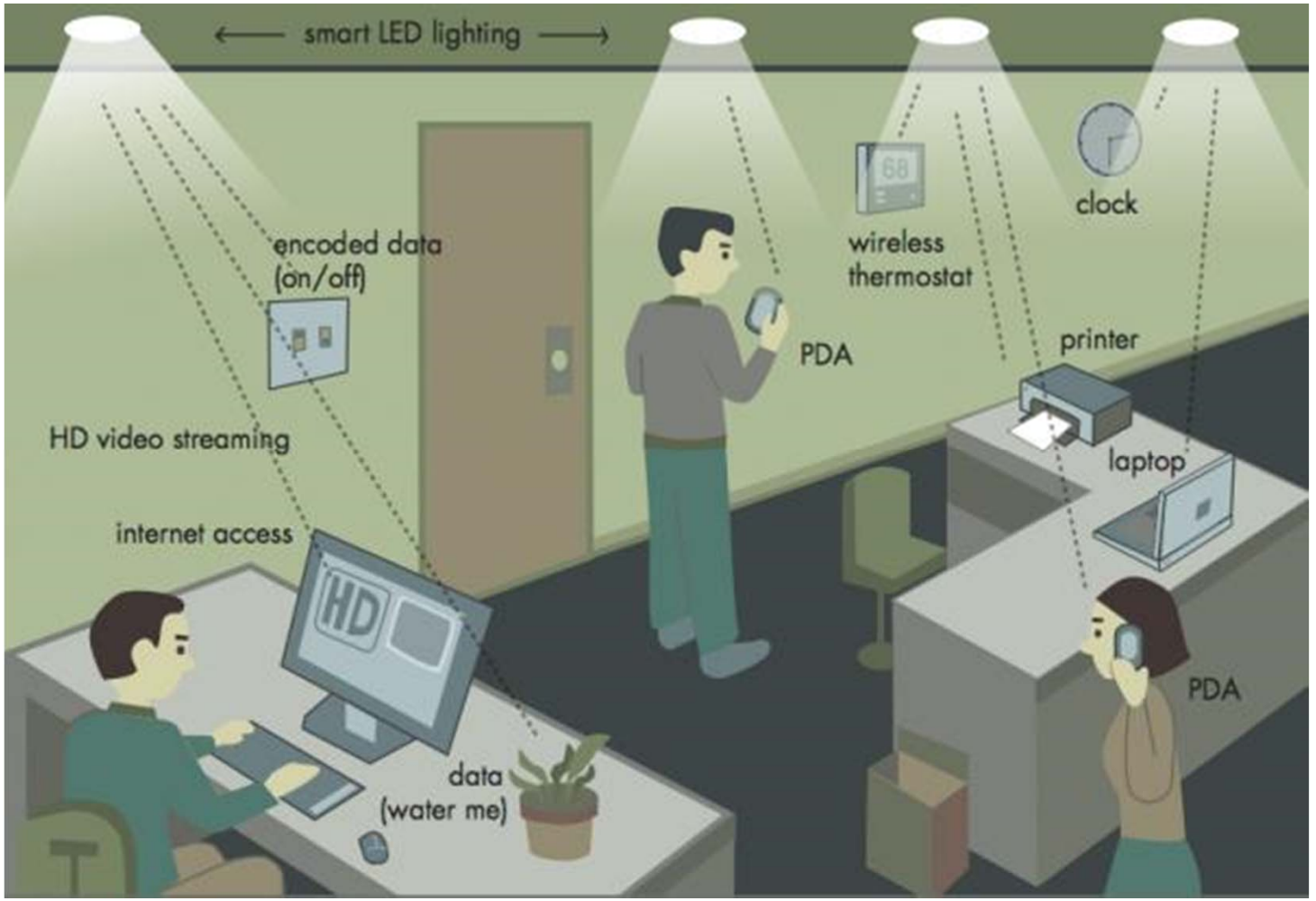
  a/b/g/n ⇒ **Data rate R** up to hundreds of Mbit/s

- Bluetooth

  R ~ tens of Mbit/s

- Optical wireless
  - Infra-red communications ⇒ R ~ Gbit/s
  - Visible light communications ⇒ R ~ hundreds of Mbit/s

OW Application: Broadband VLC



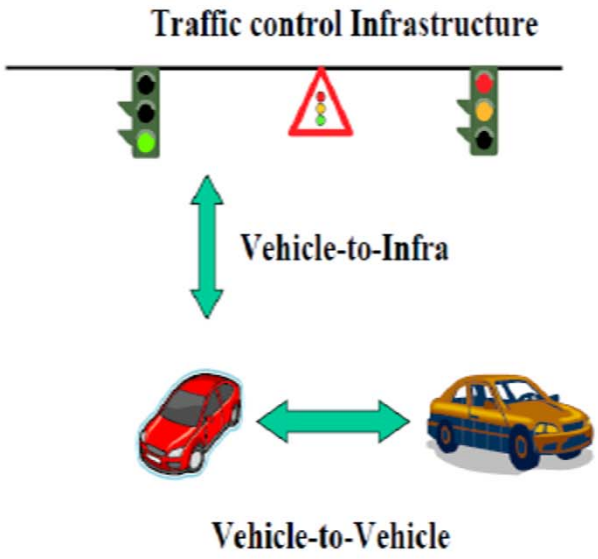
Indoor broadband broadcasting in Hospital / Supermarket / University / Office

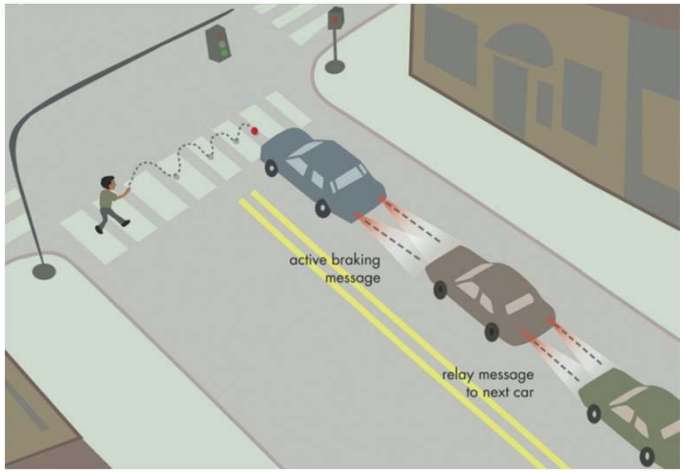
Source: Boston University

OW Application: Indoor Broadband

Source: Oxford University (OMEGA project)

OW Application: Traffic Communication





VLC Research

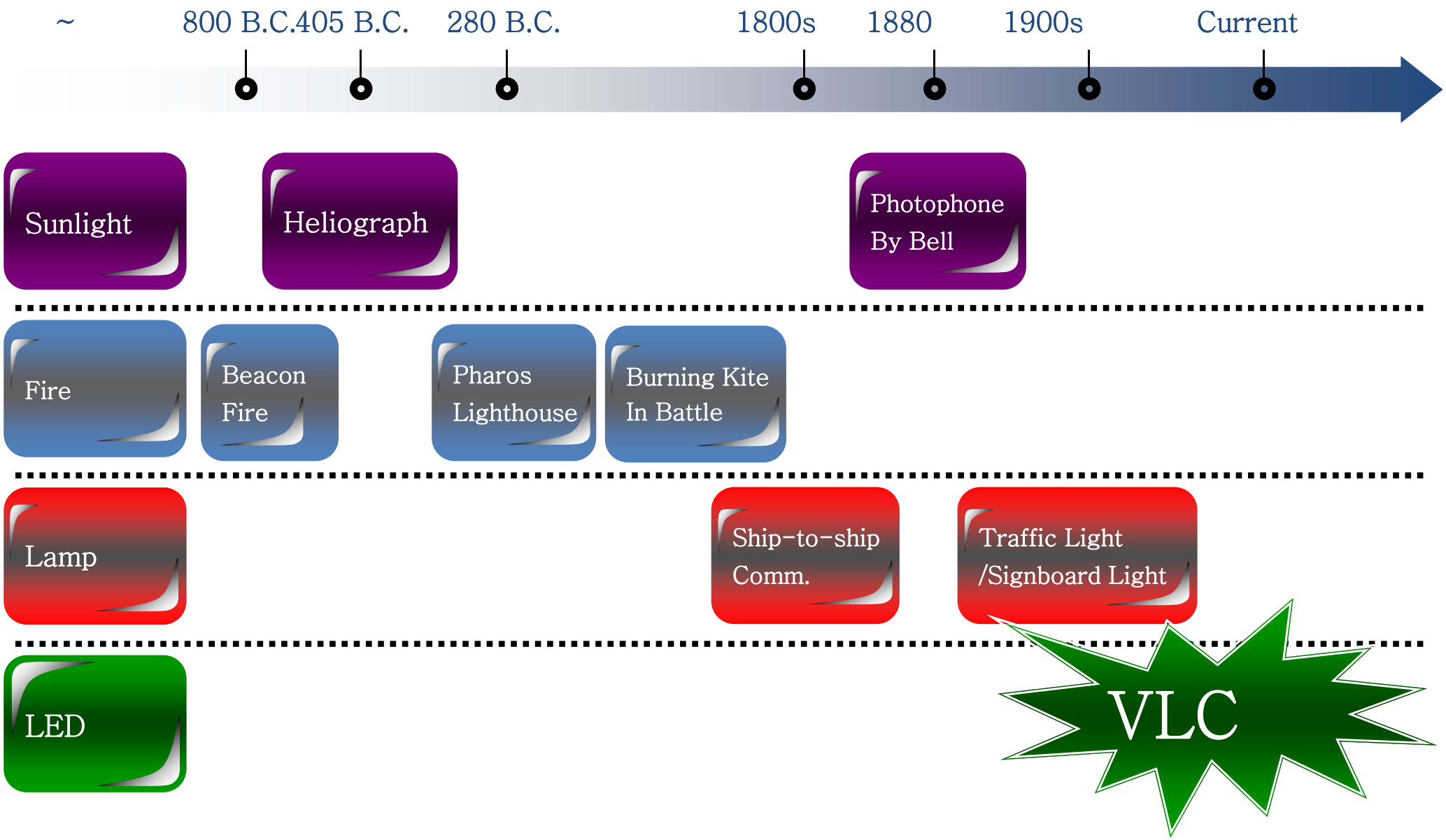
- First research can be approximately started in 1998 – 1999.
- Contribution addressing broadband VLC using WLED started in 2001.
- Currently:
  - Visible Light Communication Consortium (VLCC) was established in November 2003
    - Casio, NEC, Panasonic Electric Works, Samsung, Sharp, Toshiba, NTT, Docomo
  - OMEGA (EU Framework 7)
  - IEEE 802.15 Wireless Personal Area Network standards
  - Boston University
  - Siemens
  - France Telecom
  - Oxford University
  - Edinburgh University
  - Northumbria University

VLC Introduction

- VLC ⇒ New communication technology using "Visible Light".
  - Main purpose: General Lighting
  - Added Value: **Communication**
- Visible Light ⇒ Wavelength 400nm (750THz) – 700nm (428THz)

- General Characteristic:
  - Visibility : Aesthetically pleasing
  - Security : What You See Is What You Send.
  - Health : Harmless for human body and electronic devices
  - Unregulated : no room to use more radio frequency
  - Using in the restricted area : aircraft, spaceship, hospital
  - Eye safety

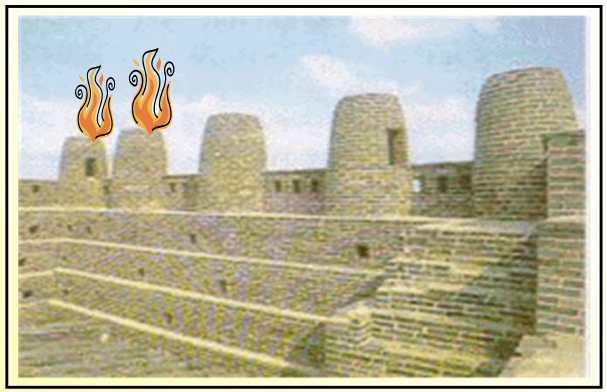
VLC History

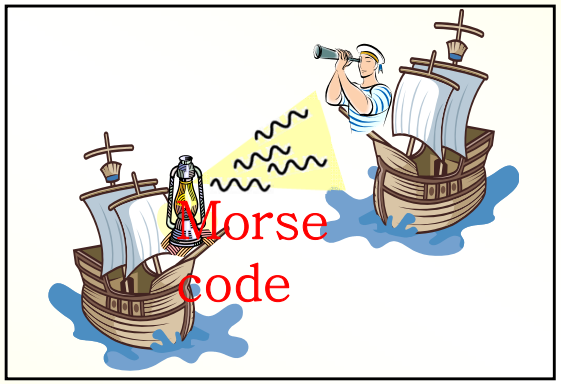

~
800 B.C.
405 B.C.
280 B.C.
1800s
1880
1900s
Current
Sunlight
Heliograph
Photophone By Bell
Fire
Beacon Fire
Pharos Lighthouse
Burning Kite In Battle
Lamp
Ship-to-ship Comm.
Traffic Light /Signboard Light
LED
VLC

VLC history – Low Speed

- Information delivery through reflection by mirror (Heliograph)
- The use of fire or lamp
  - Beacon fire, lighthouse, ship-to-ship comm. by Morse code
- Traffic light : signal discrimination by color (Walk/Stop)

Beam reflection (directional)

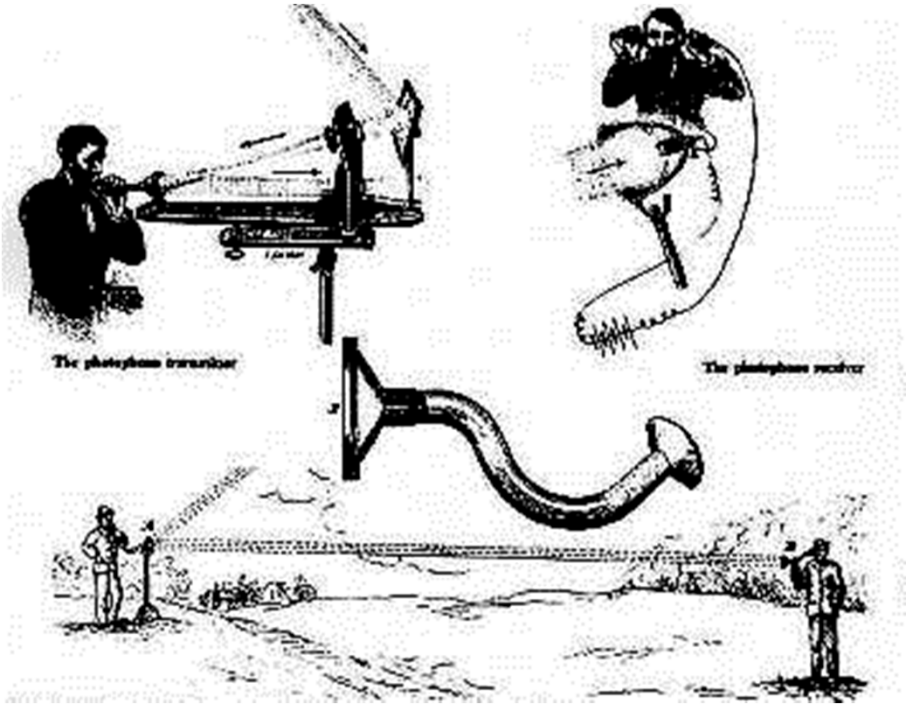




❑ In 1880, Alexander Graham Bell invented the photophone

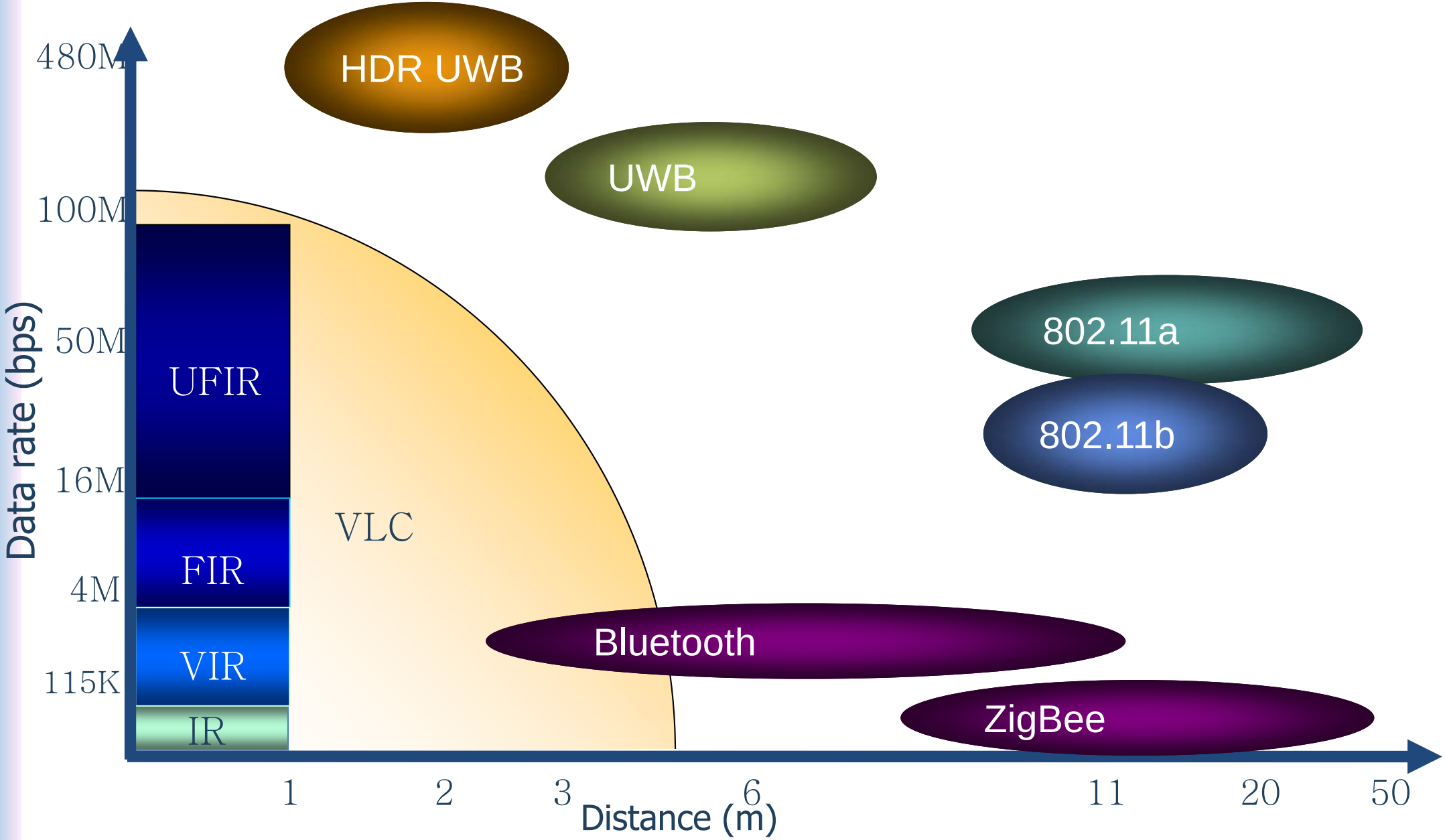
- BOptical source : sunlight
- Externally modulation by vibrating mirror
- Receiver : parabolic mirror with crystalline selenium cells
- 700 ft (213m) sound transmission

http://www.freespaceoptic.com/



Excerpted from: The New Idea Self-Instructor edited by Ferdinand Ellsworth Cary, A. M. (Monarch Book Company, Chicago & Philadelphia, 1904)

VLC Characteristics



VLC vs. Infrared (IR) and Radio-frequency(RF)

Property	VLC	IRB	RFB
Bandwidth	Unlimited, 400–700 nm	Unlimited, 800–1600 nm	Regulated and limited
Electromagnetic interference + hazard	No	No	Yes
Line of sight	Yes	Yes	No
Distance	Short	Short to long (outdoor)	Short to long (outdoor)
Security	Good	Good	Poor
Standards	In progress (IEEE 802.15.7 Task Group)	Well developed for indoor (IrDa), In progress for outdoor	Matured
Services	Illumination + communications	Communications	Communications
Noise sources	Sun light + other ambient lights	Sun light + other ambient lights	All electrical/ electronic appliances
Power consumption	Relatively low	Relatively low	Medium
Mobility	Limited	Limited	Good
Coverage	Narrow and wide	Narrow and wide	Mostly wide

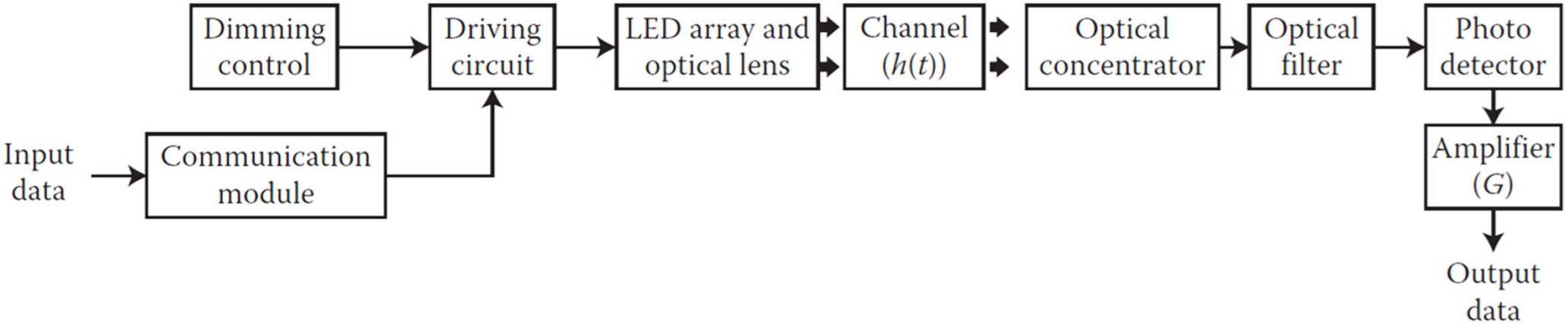
VLC Motivation

- Communication community trend
  - Ubiquitous (Connect each other everywhere, every time)
  - Security
- LED trend
  - LED technology (efficiency, brightness)
  - LED Cost
- Environmental trend
  - Health
  - Energy saving
- Intrinsic characteristic of VLC
  - Visibility
  - No interference / No regulation

VLC System

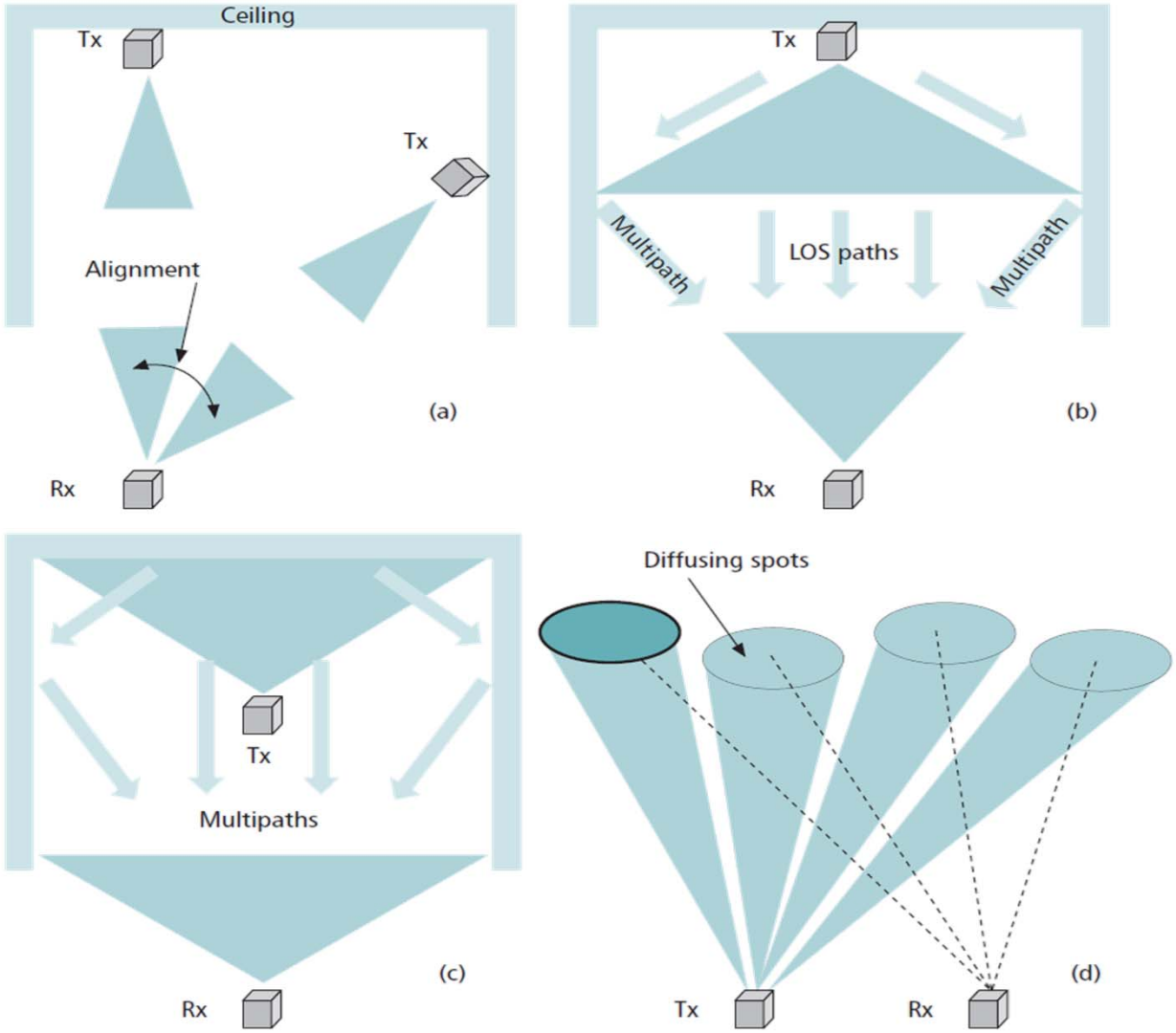
Block Diagram of a VLC System

- Precise dimming appears to be challenging for incandescent and gas-discharge lamps
  - With LEDs it is quite convenient to accurately control the dimming level



Indoor VLC Configurations

- Generally, 4 configurations for indoor optical links[1]
  - (a) Directed – line-of-sight link
  - (b) Non-directed LOS link
  - (c) Diffuse link
  - (d) Quasi diffuse link



[1] H. Elgala, R. Mesleh, and H. Haas, "Indoor optical wireless communication: Potential and state-of-the-art," *IEEE Commun. Mag.*, vol. 49, no. 9, pp. 56 – 62, Sep 2011.

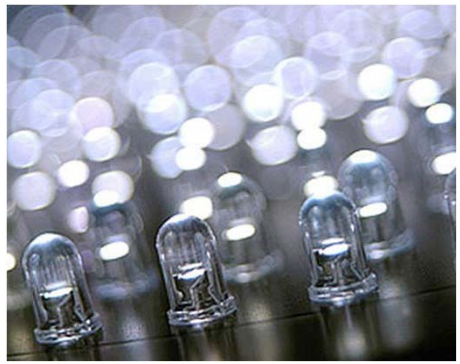
Light Source

General Lighting Sources

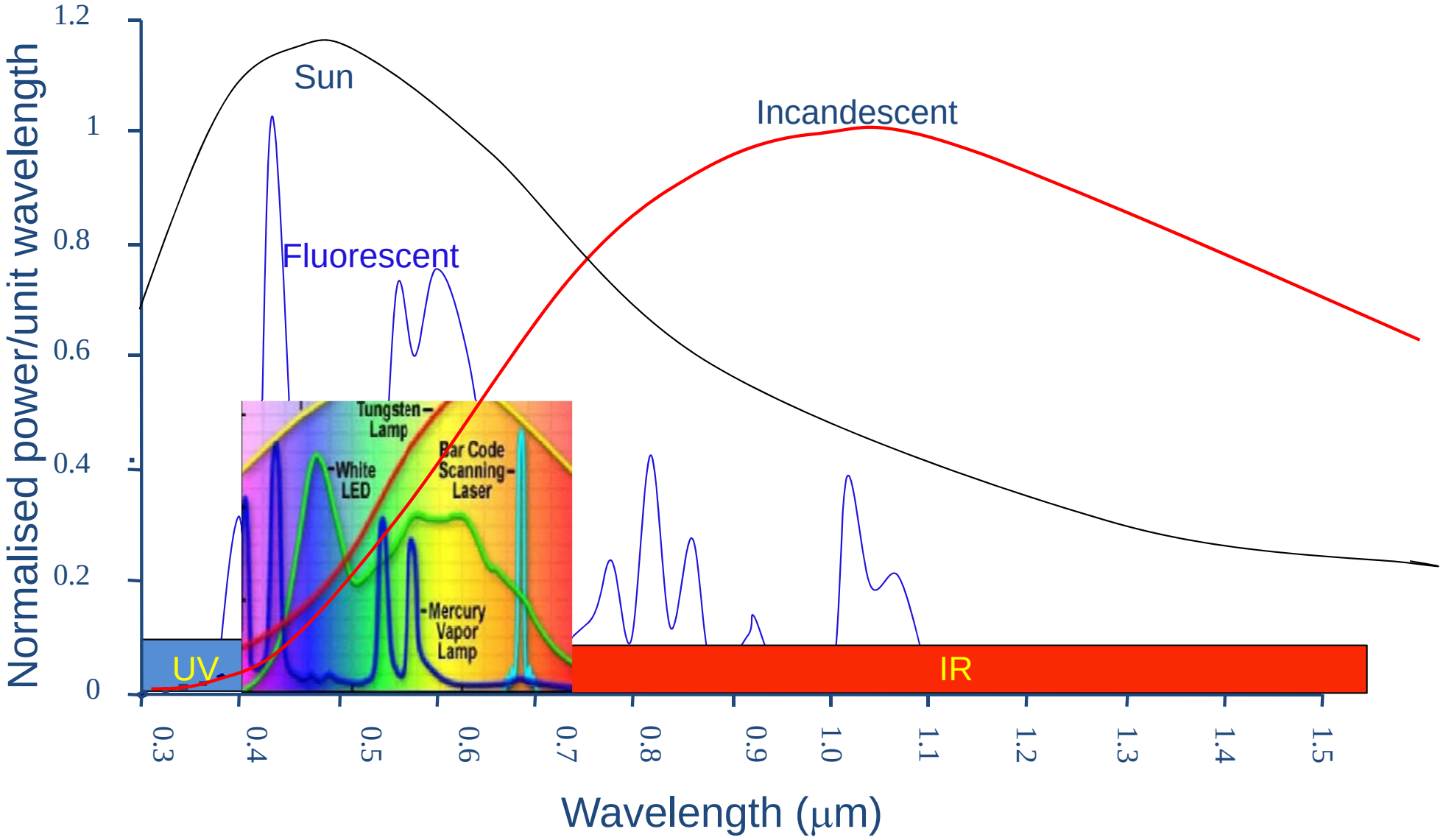
- Incandescent bulb
  - First industrial light source
  - 5% light, 95% heat
  - Few thousand hours of life

- Fluorescent lamp
  - White light
  - 25% light
  - 10,000s hours

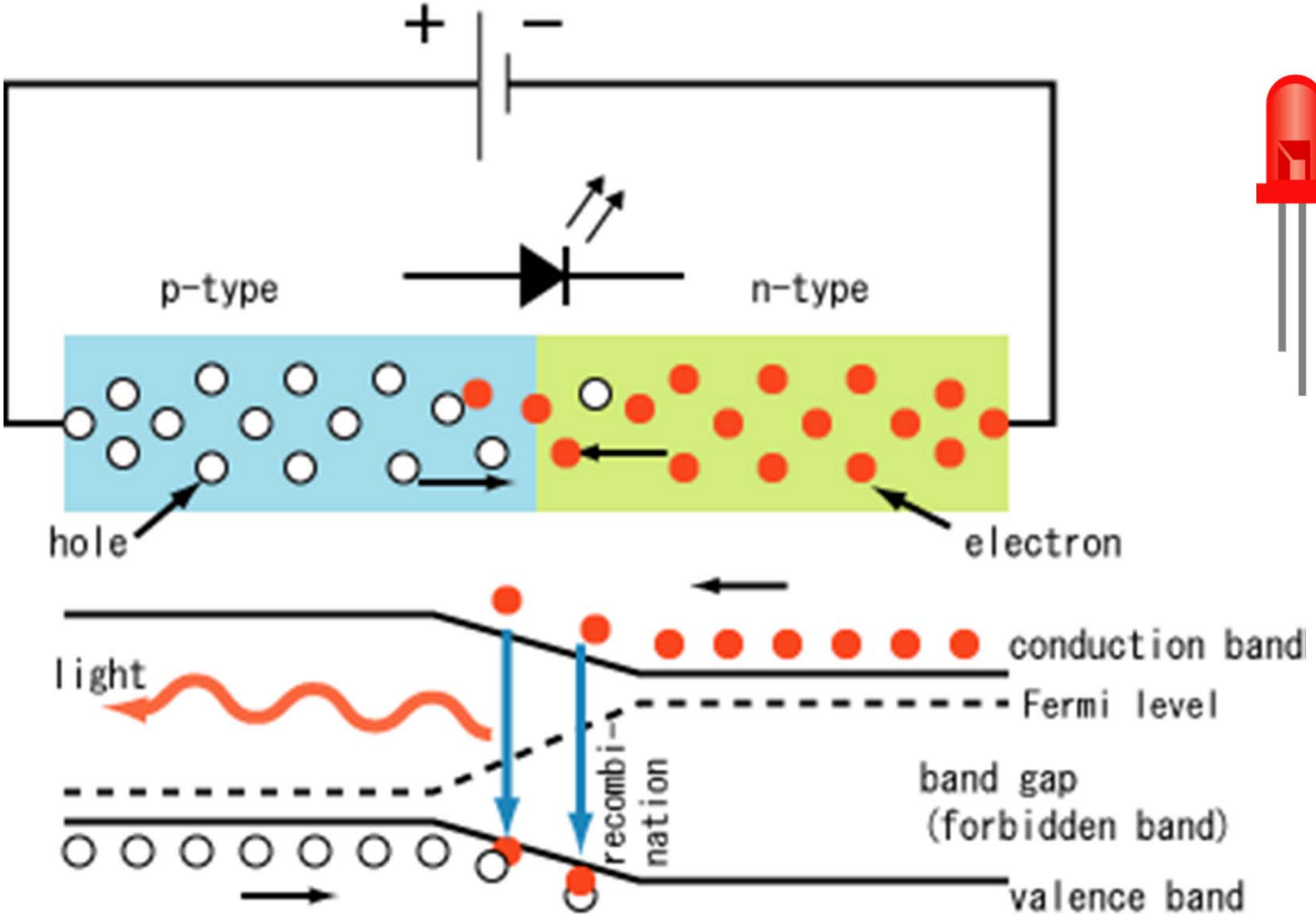
- Solid-state light emitting diode (LED)
  - Compact
  - 50% light
  - More than 50,000 hours lifespan

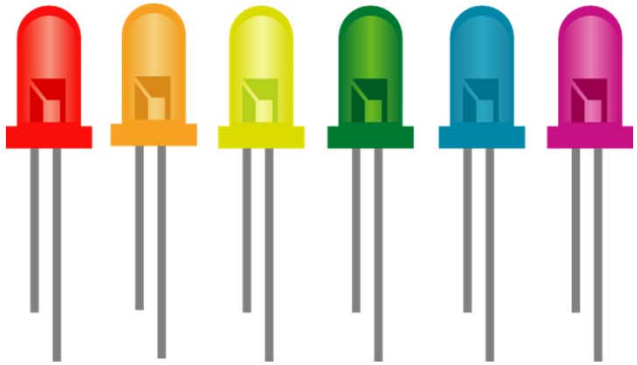


Light Source Spectrum



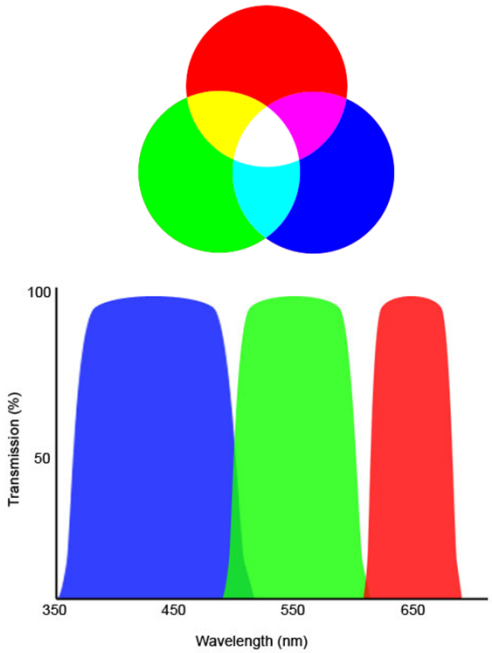
What is Light Emitting Diode (LED)?





White-Light LED

RGB



Well-known technology, limited use, problem with balancing each R, G, B component to create white light

Blue chip + Phosphor

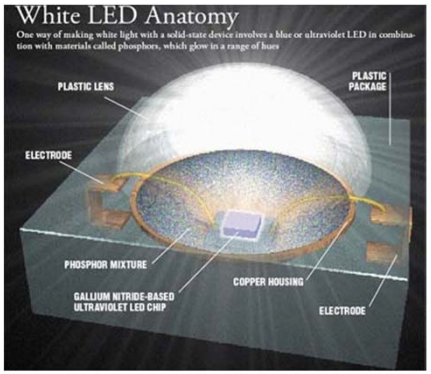
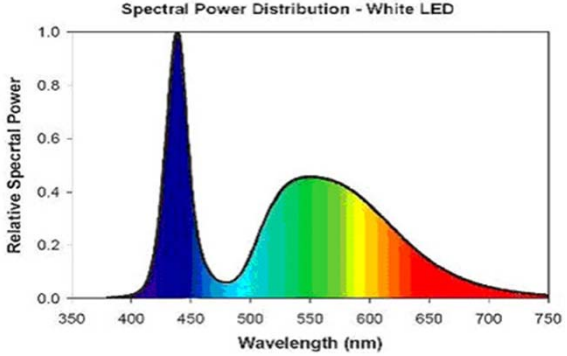
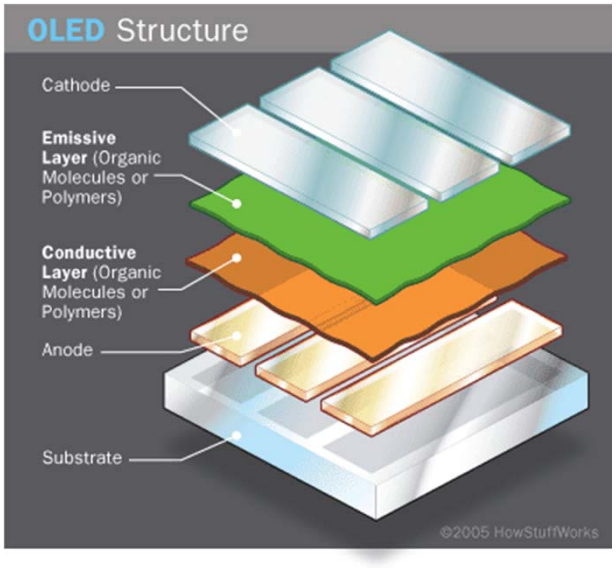


Figure 6. In this one-watt seven-millimeter device from GELcore,



Popular for today general lighting, efficient and cheap

OLED



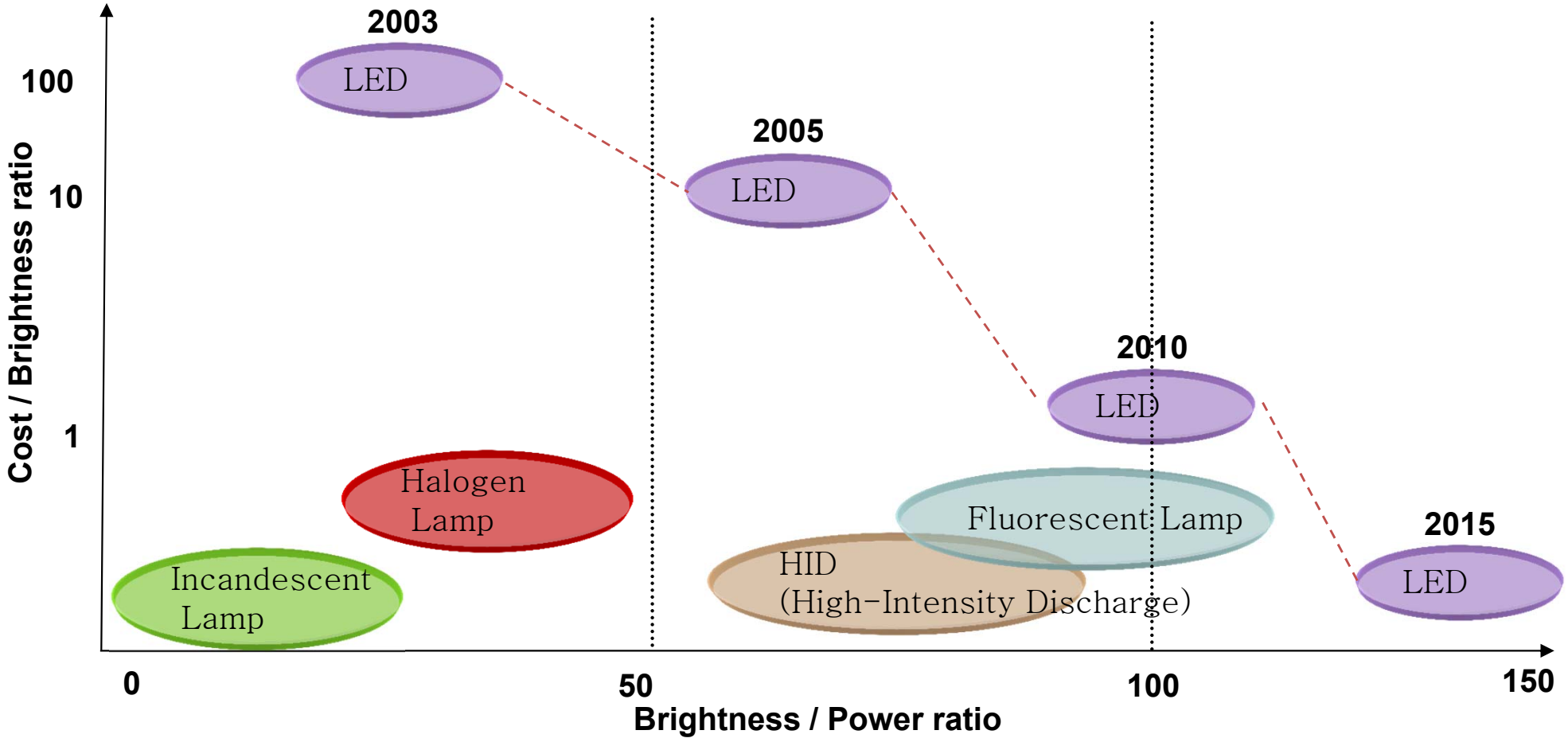
New technology, expensive and short life time. It is, however, very potential

LED as Light Source for VLC

Light Emitting Diode (LED)

- Eye-safety regulations (compared to Laser)
- Longevity
- Lower cost
- Are mercury free
- Less consumption
- High speed
- Have smaller and compact size
- Minimum heat generation
- higher tolerance to humidity
- A much higher energy conversion efficiency
  - White LEDs with luminous efficacy greater than 200 lm/W are now available

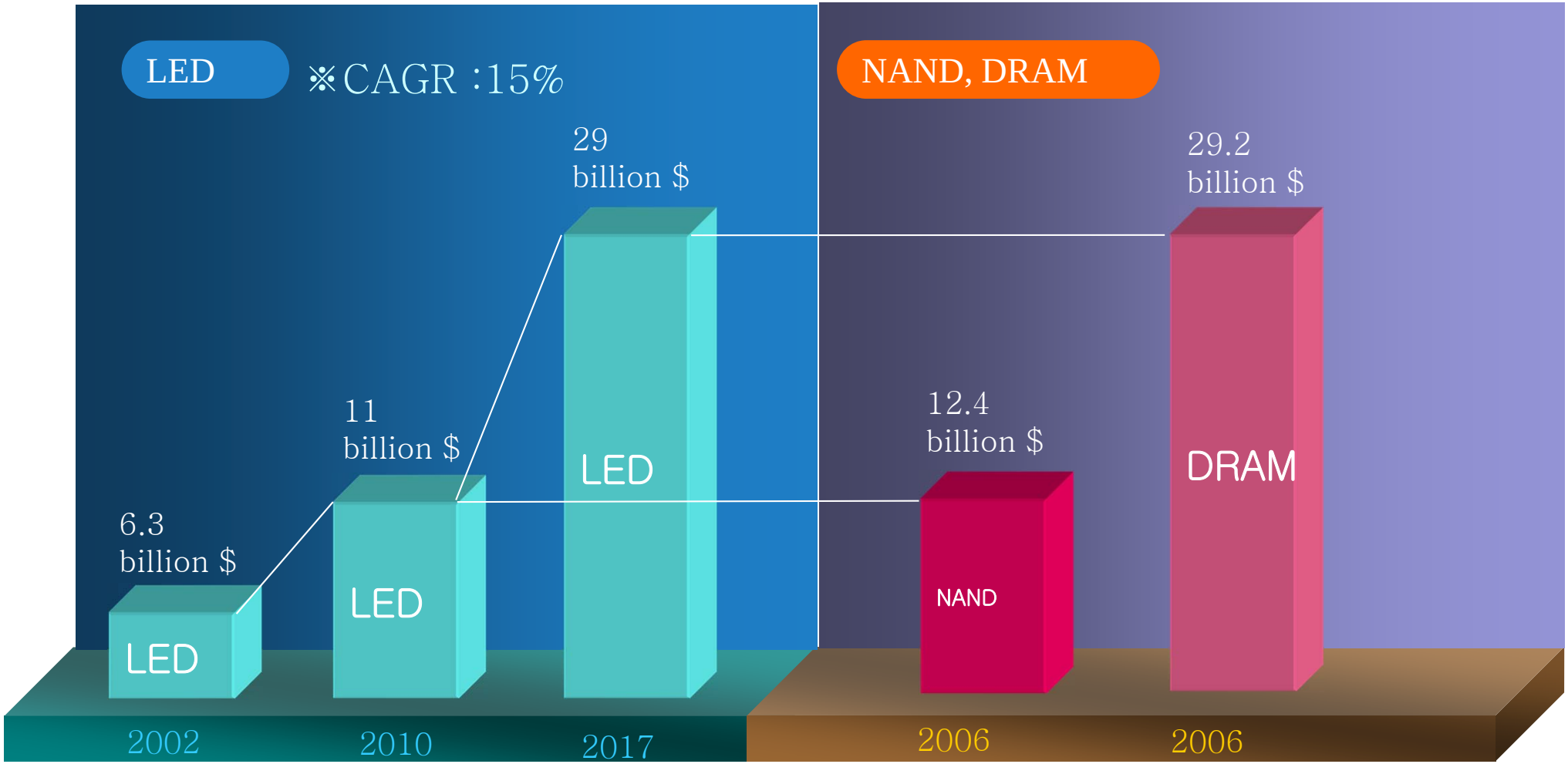
❑ Performance and Price comparison



Source: Credit Suisse, 2006.11.2

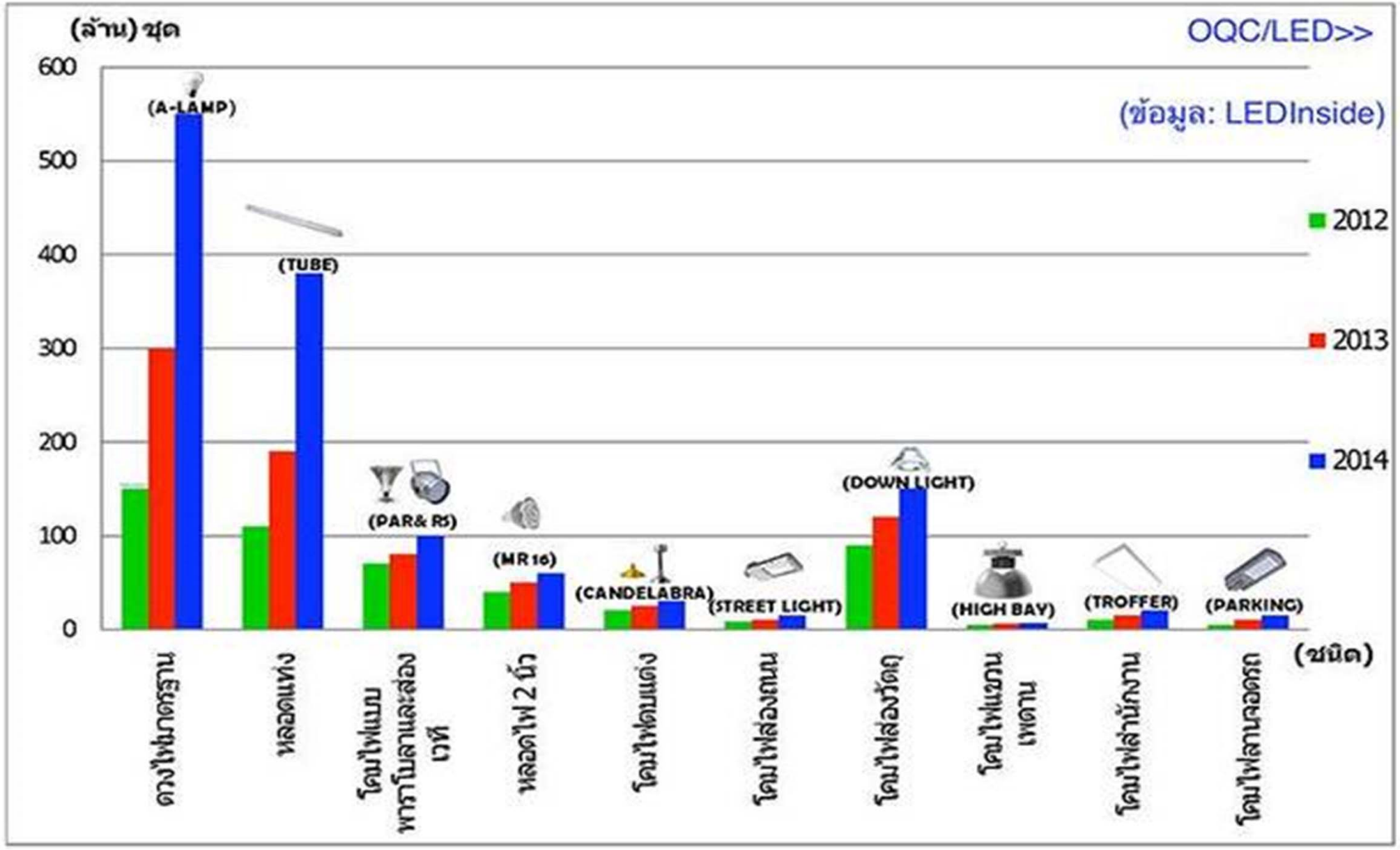
LED Market Forecast

❑ LED market comparison with NAND, DRAM



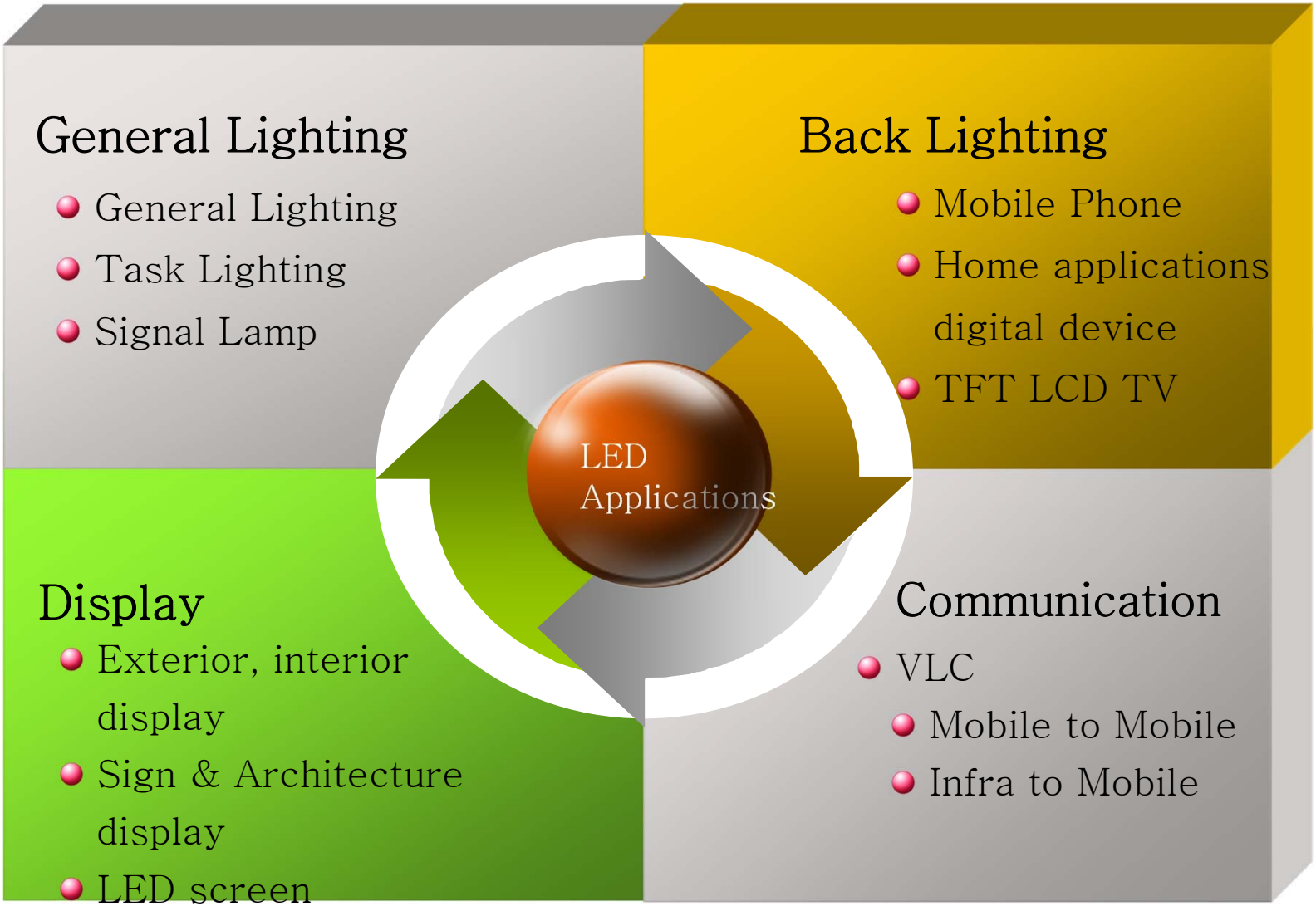
Source: Deutsche Bank, 2007. 2

#LEDs Used in Thailand



Source: www.google.com

LED Application



VLC Applications

Bandwidth
Security

1nm
UV
380nm
visible
780nm
IR
100μm
3cm
RF
1m

Coverage
Mobility

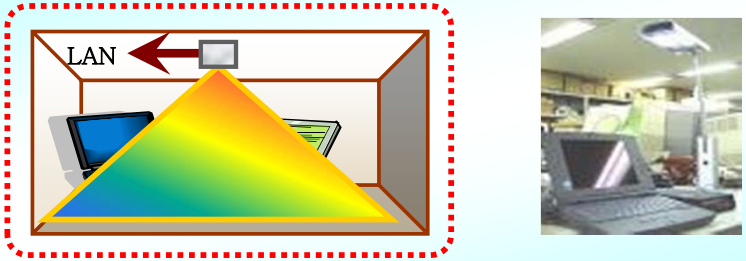
Peripheral Interface

Contents Machine
e-book
Sign Board
ITS (Navigation)

Information Broadcast

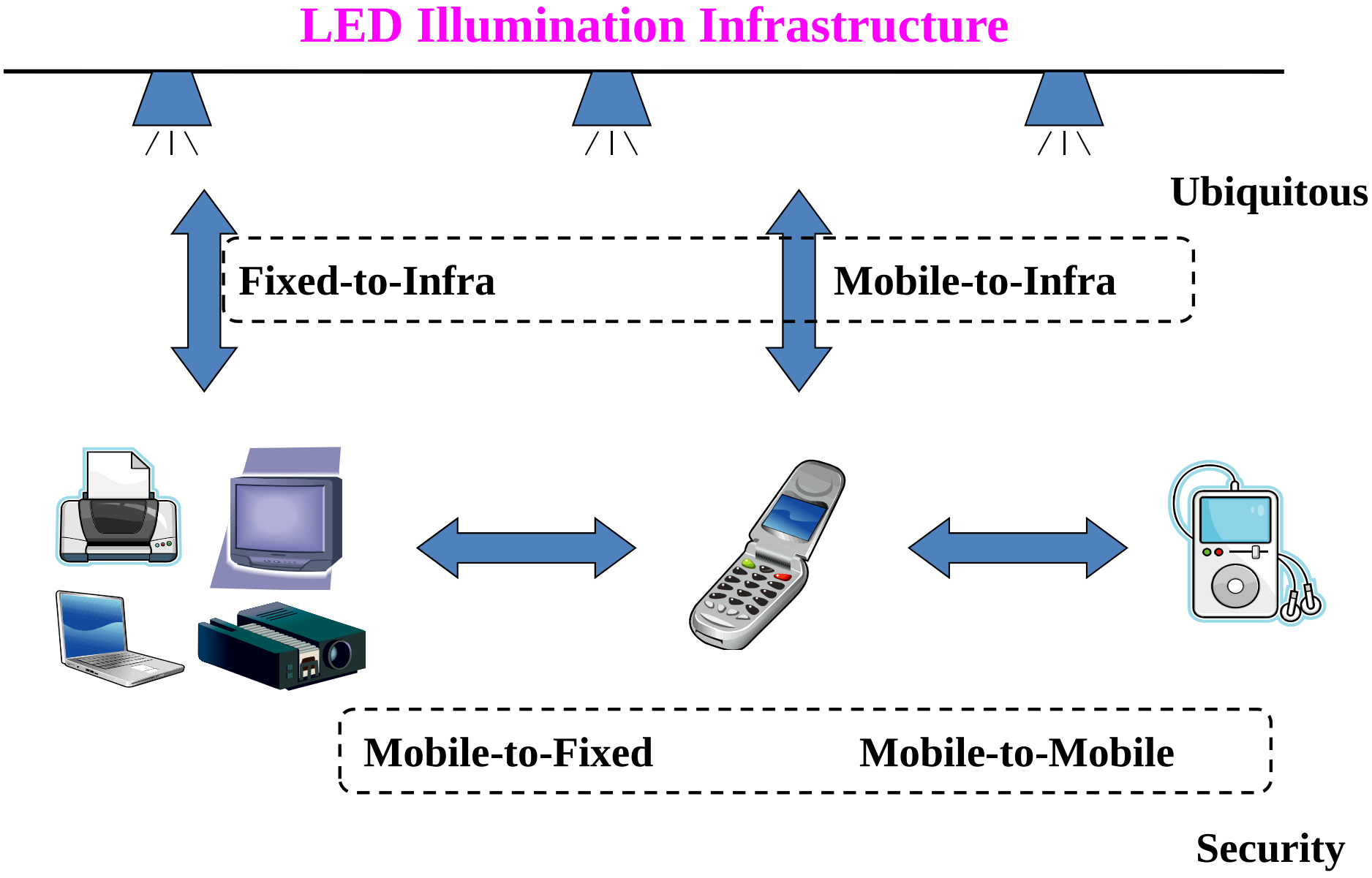
Digital Hospital
Security
Banking
Door Lock
In Plane

RF Prohibited



Visible LAN

Indoor Applications



Requirements (Indoor Application)

	Mobile to Mobile	Mobile to Fixed	Mobile to Infra	Fixed to Infra
Link	Bi-direction	Bi-direction	Bi or Uni	Bi or Uni
Reach	~1m	~1m	~3m	~3m
Rate	~100M	~100M	~10M	~10M
Application	Contents sharing	File transfer Video streaming M-commerce	Indoor navigation LBS Networked robot	Data broadcast
Alternative	IrDA, Bluetooth, UWB	IrDA, Bluetooth, UWB		WLAN

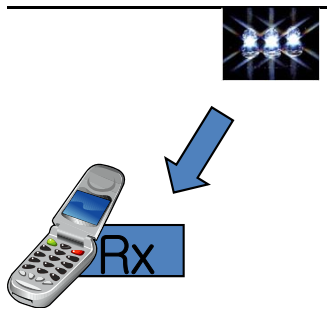
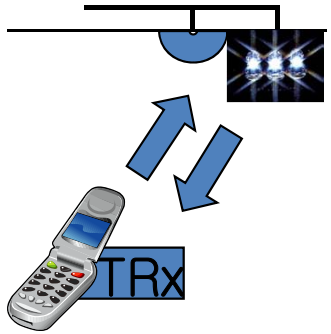
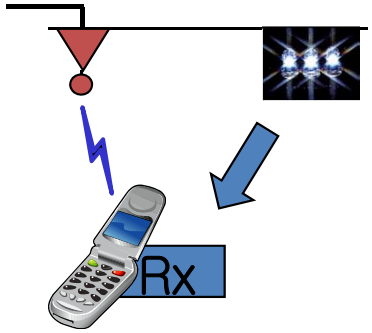
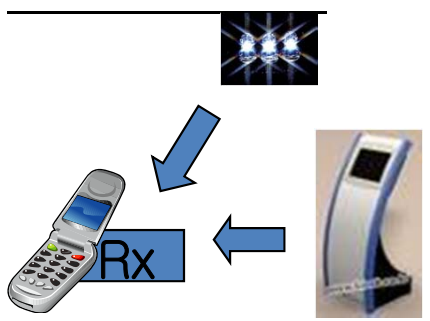
❑ Advantages

- ➢ Safe for health
- ➢ Secure
- ➢ No interference on RF signals
- ➢ High speed
- ➢ Confined to small geographical area

❑ Challenging Problems

- ➢ Connectivity while moving
- ➢ Multiuser support
- ➢ Dimming
- ➢ Shadowing
- ➢ Confined to small geographical area

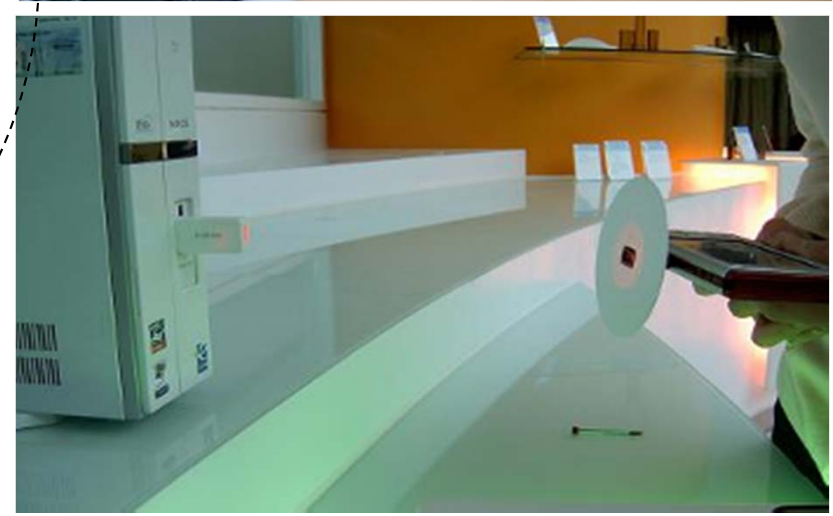
Indoor navigation scheme

	Uni-direction	Bi-direction	Hybrid	Hot spot
Link				
Rate	■ Down : ~10k	■ Down : ~10M ■ Up : ~100M	■ Down : ~10k ■ Up : ~10M	■ Down(light) : ~10k ■ Down(HS) : ~100M
Infra	■ Lighting with optical ID	■ Lighting with optical ID ■ Receiver ■ In-building network ■ Routing server	■ Lighting with optical ID ■ RF access point ■ In-building network ■ Routing server	■ Lighting with optical ID ■ Hot spot
Mobile	■ Receiver ■ Large storage ■ Map info ■ Routing software	■ Receiver ■ Transmitter	■ Receiver ■ RF connectivity	■ Receiver ■ Large storage ■ Routing software
Other service		LBS Ad-hoc connection	LBS	

High-Speed High-Security Connectivity

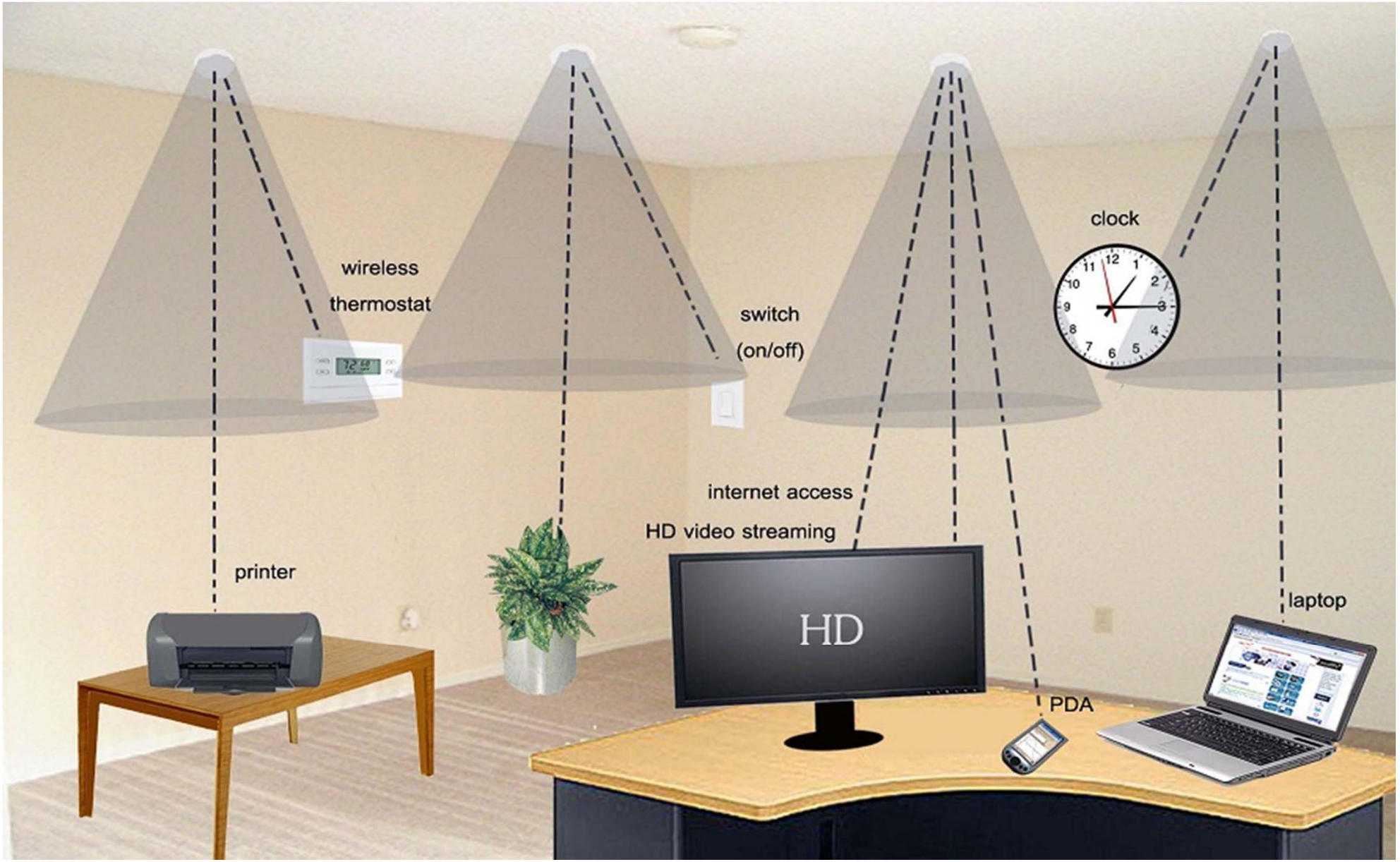
What You See Is What You Send (WYSIWYS)

E-Contents Vending Machine



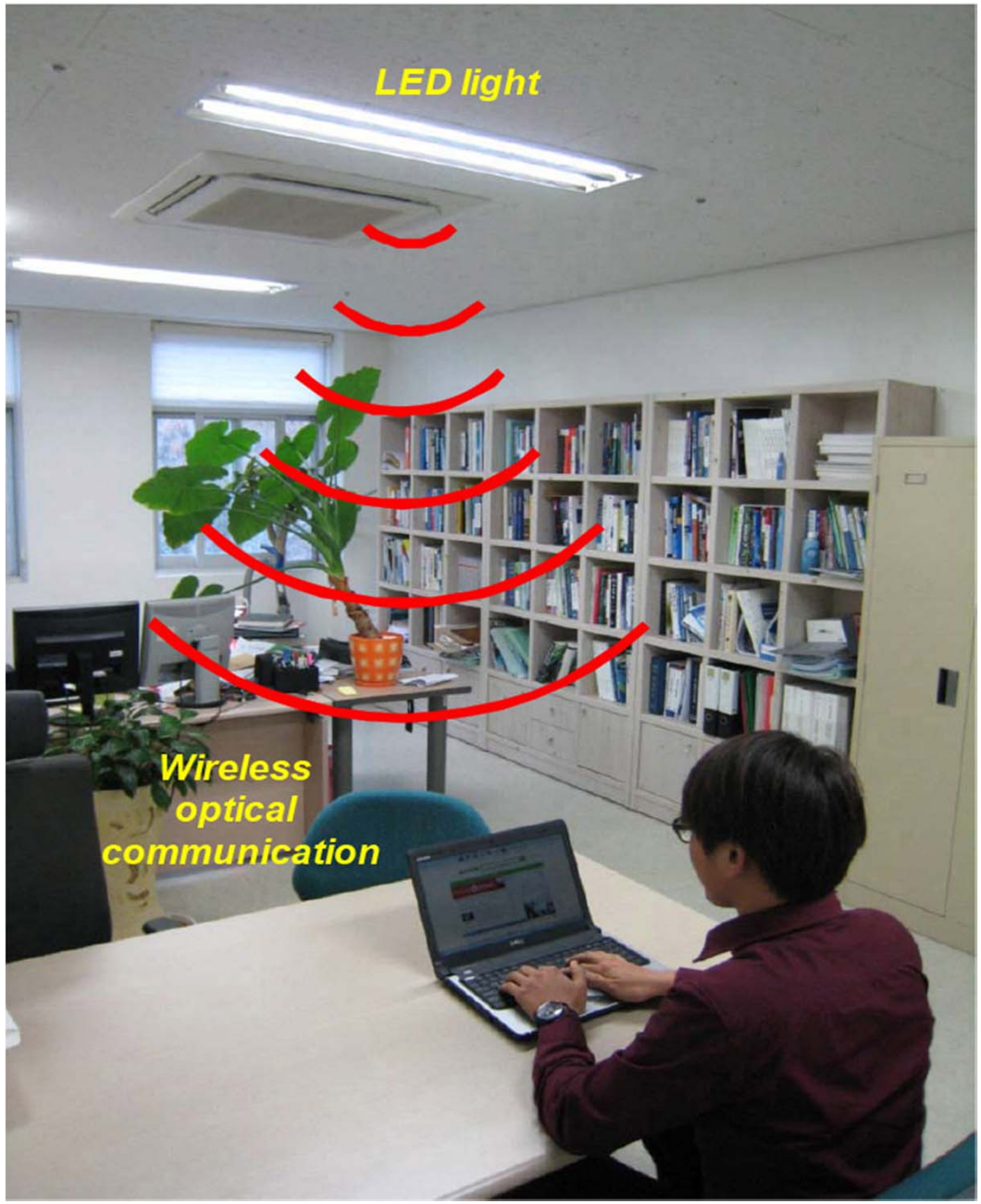
► Visible Light Communication ◄

❑ In Office Room



www.google.com

❑ In Building



www.google.com

❑ In Airplane

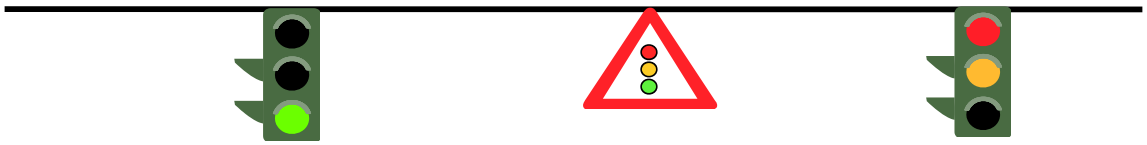
www.google.com

❑ In hospital

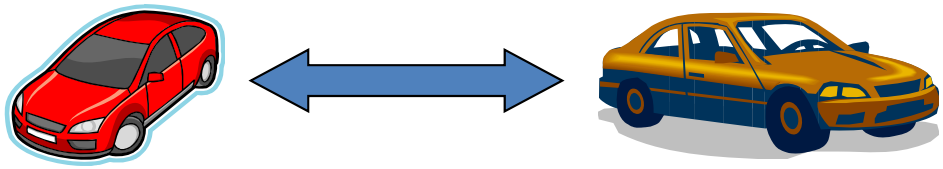
www.google.com

Outdoor Applications

Traffic control Infrastructure



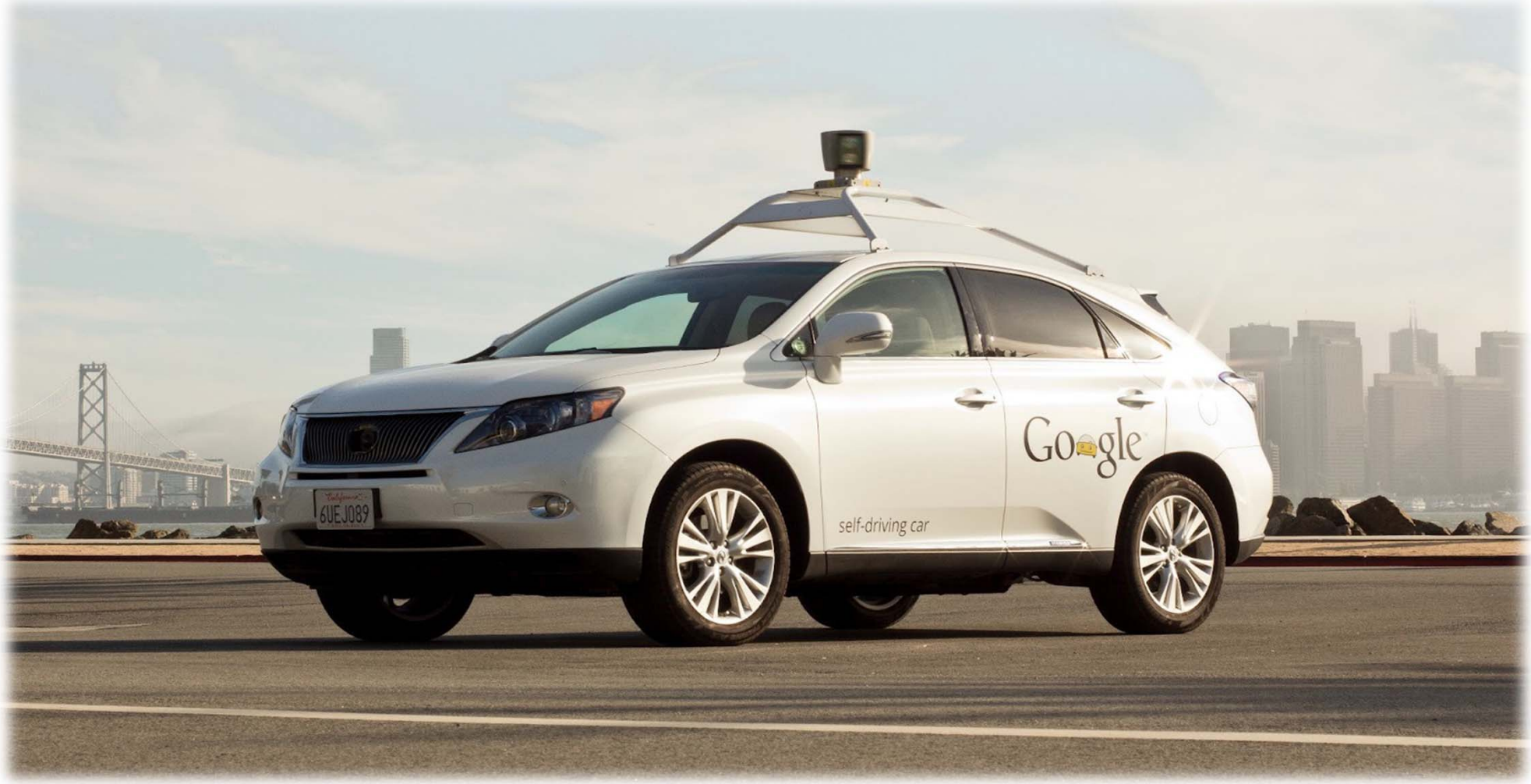
Vehicle-to-Infra



Vehicle-to-Vehicle

Outdoor advertising

❑ รถยนต์ไร้คนขับ



www.google.com

VLC Demonstration

High speed

Mobile to Mobile
(100Mbps,Samsung)

Tx, Rx
(~30Mbps,Oxford Univ.)

LED array
(~1Gbps, Keio Univ.)

Music broadcasting
(6Mbps, Oxford Univ.)

Infra to Mobile
(10Mbps, Tamura Inc.)

Sign board
(10Mbps, Samsung)

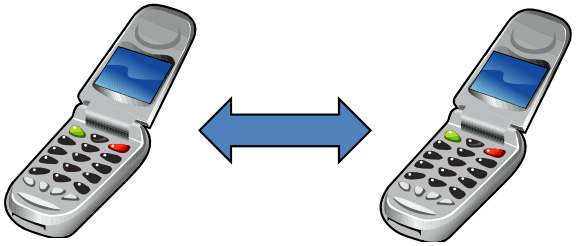
Infra to Mobile(VLAN)
(4Mbps, Samsung)

Low speed

Audio system
(100kbps, Hongkong Univ.)

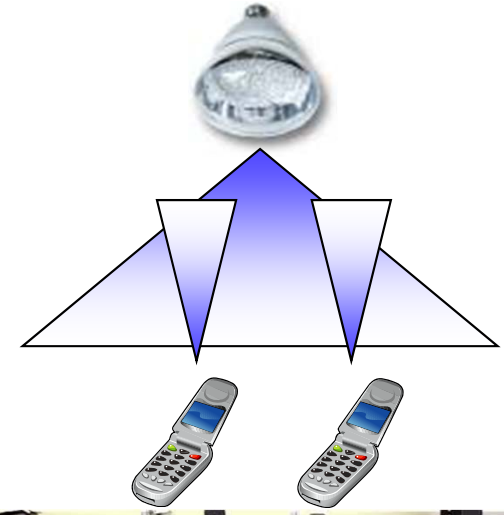
Infra to Mobile, VLCC (Keio Univ., NEC, Toshiba, Sony, Matsushita, Casio etc.)
(4.8kbps, illuminations, visible light ID, sign board, applications based on JEITA)

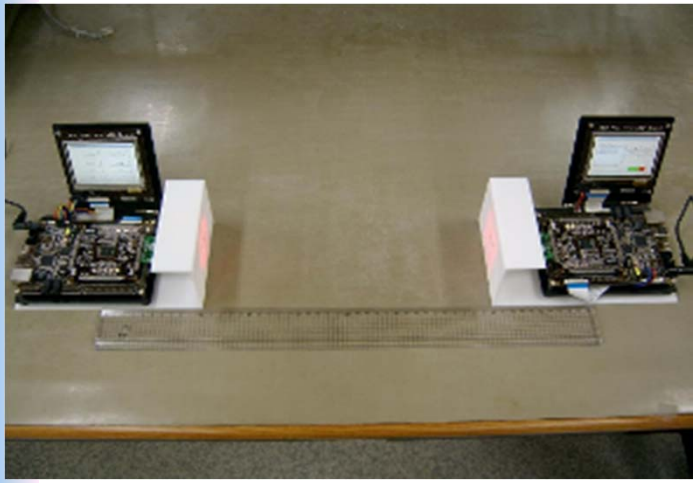
Mobile to mobile



Infra to mobile

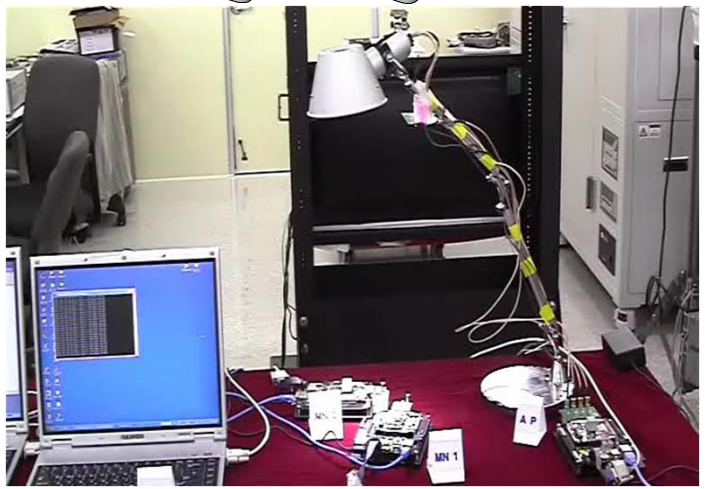
Infra to mobile





100 Mb/s
1m
Bidirection

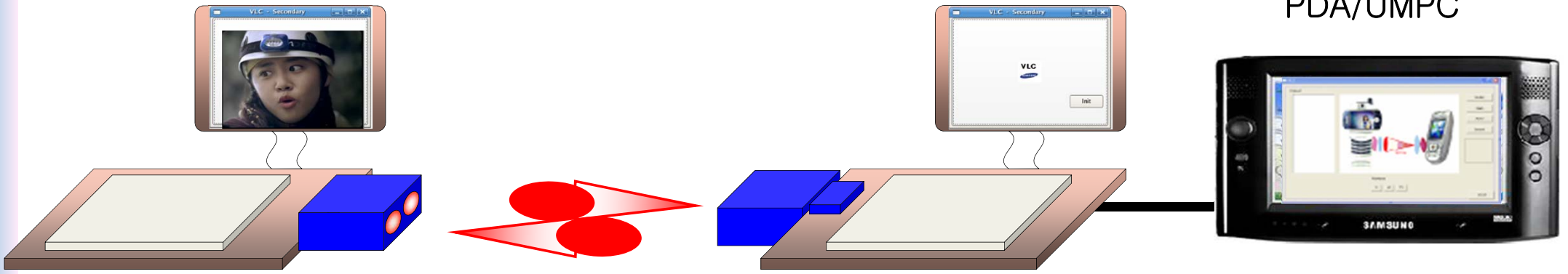
20 Mb/s
3m
Unidirection

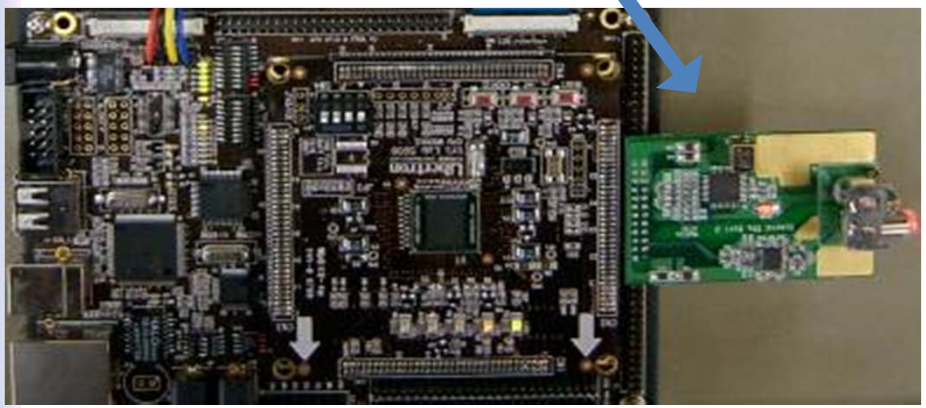


4 Mb/s
3m
Bidirection

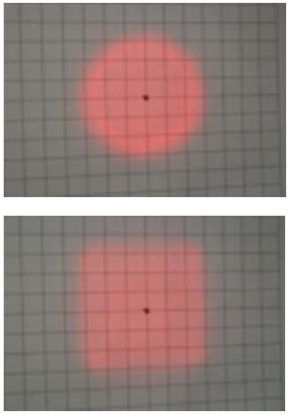
Mobile-to-mobile demo

- What You See Is What You Send (WYSIWYS)
- 120 Mb/s, 1m, Full duplex
- File transfer and video streaming

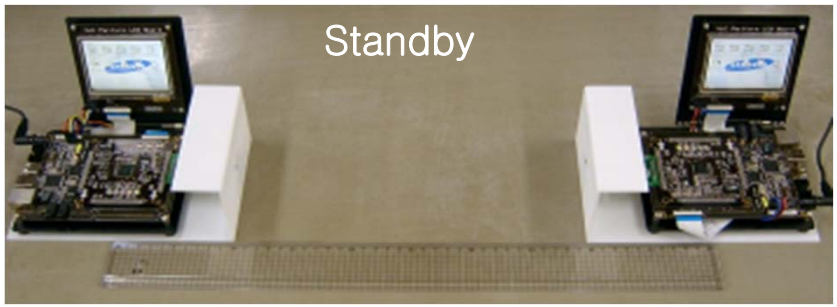


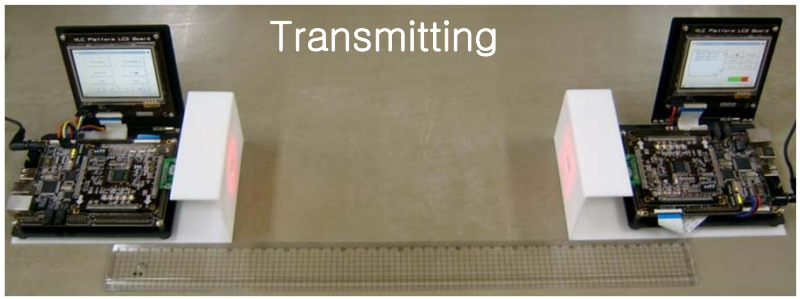


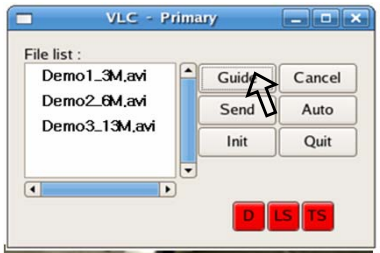
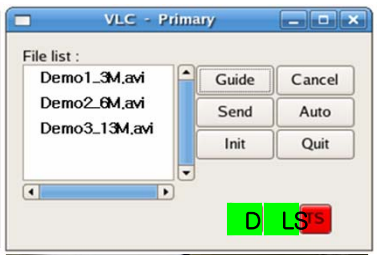
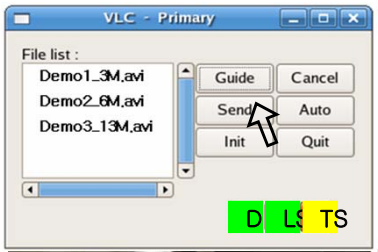
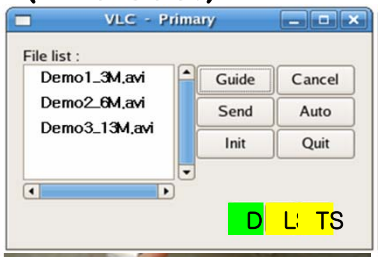
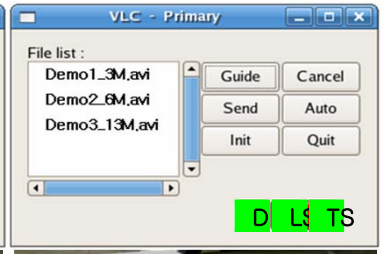
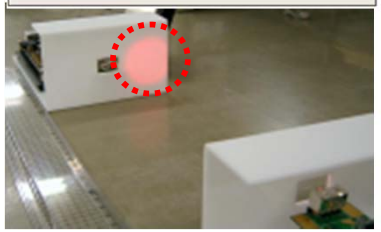
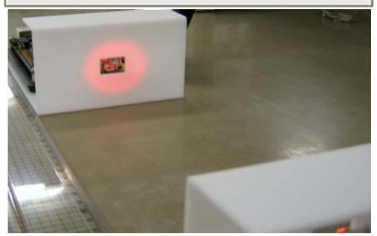
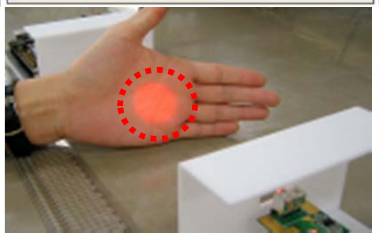
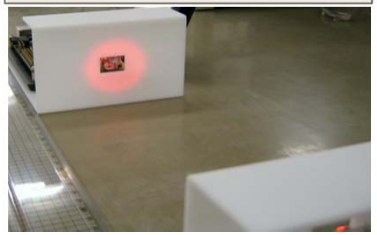
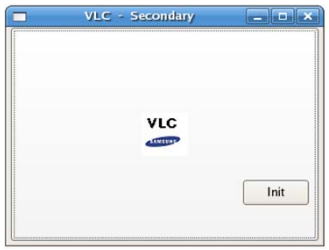
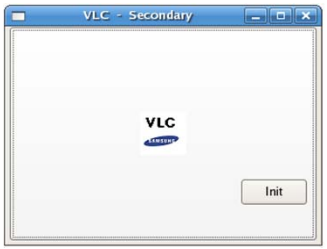
Spot @ 30 cm



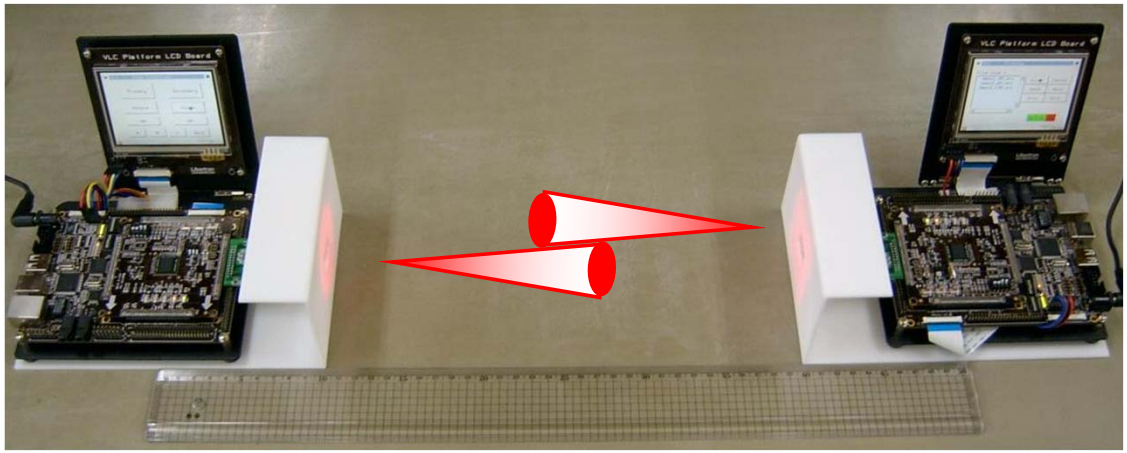
Mobile-to-mobile (protocol)

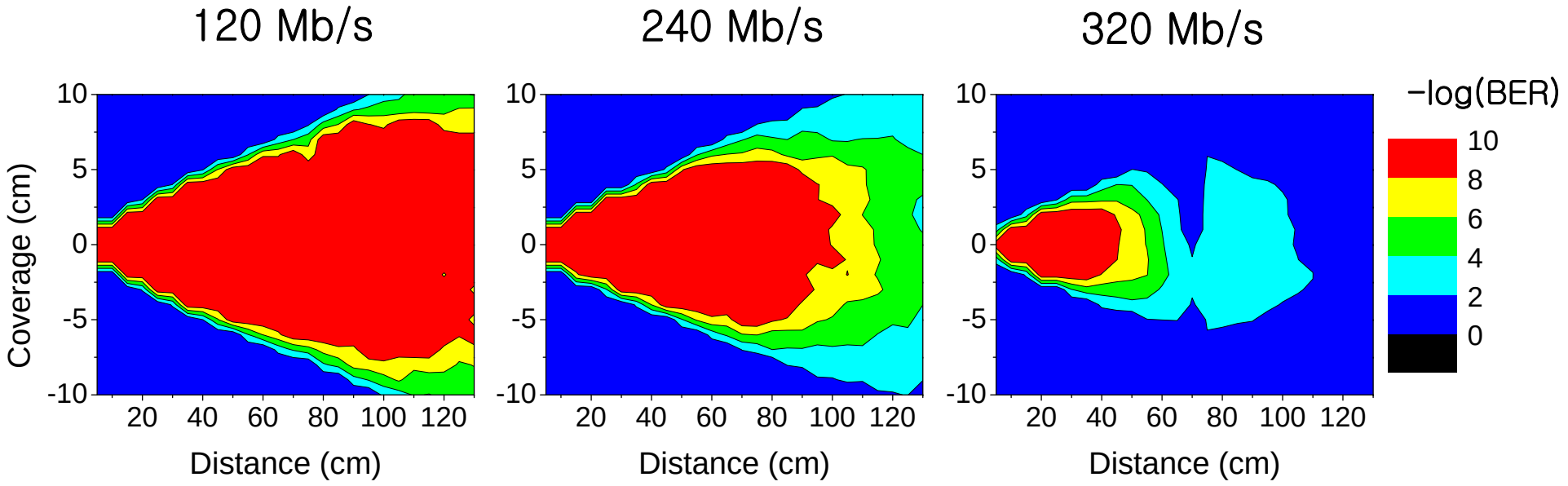




	Beam guiding	User alignment Device discovery	Start steaming	Temporal blocking (< 8 sec.)	Streaming end
Primary Screen					
Link					
Secondary Screen					

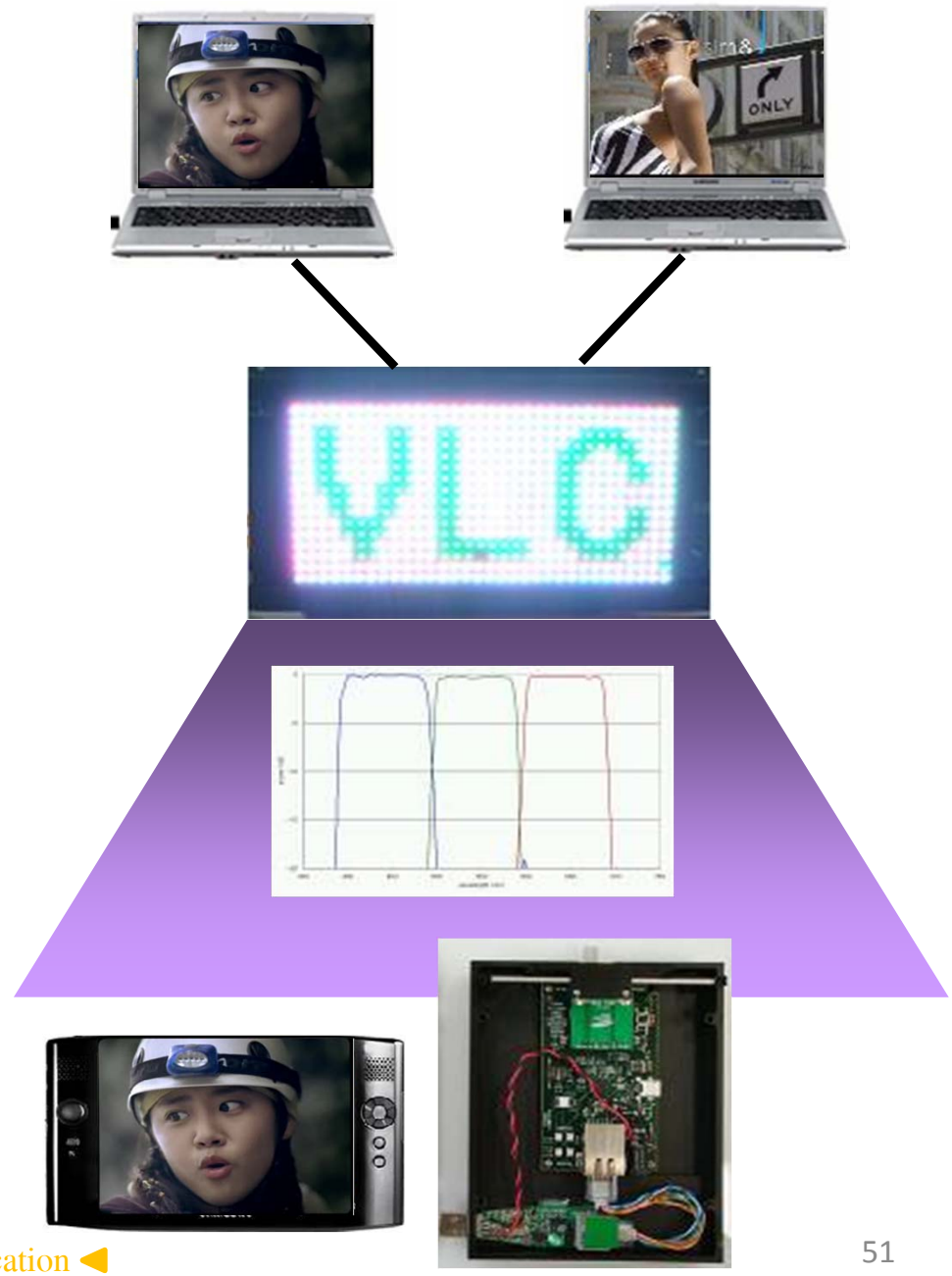
Mobile-to-mobile (Link performance)





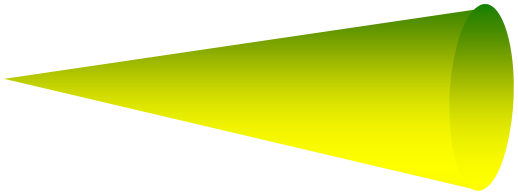
Infra-to-mobile demo

- RGB WDM transmission
- 20 Mb/s, 3m, Uni-direction
- Information broadcast from sign board

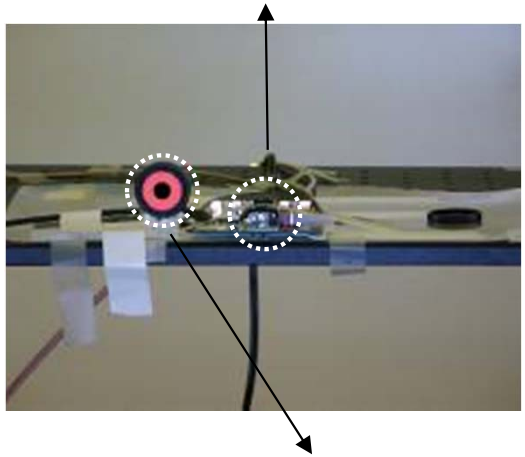


Infra-to-mobile (Link performance)

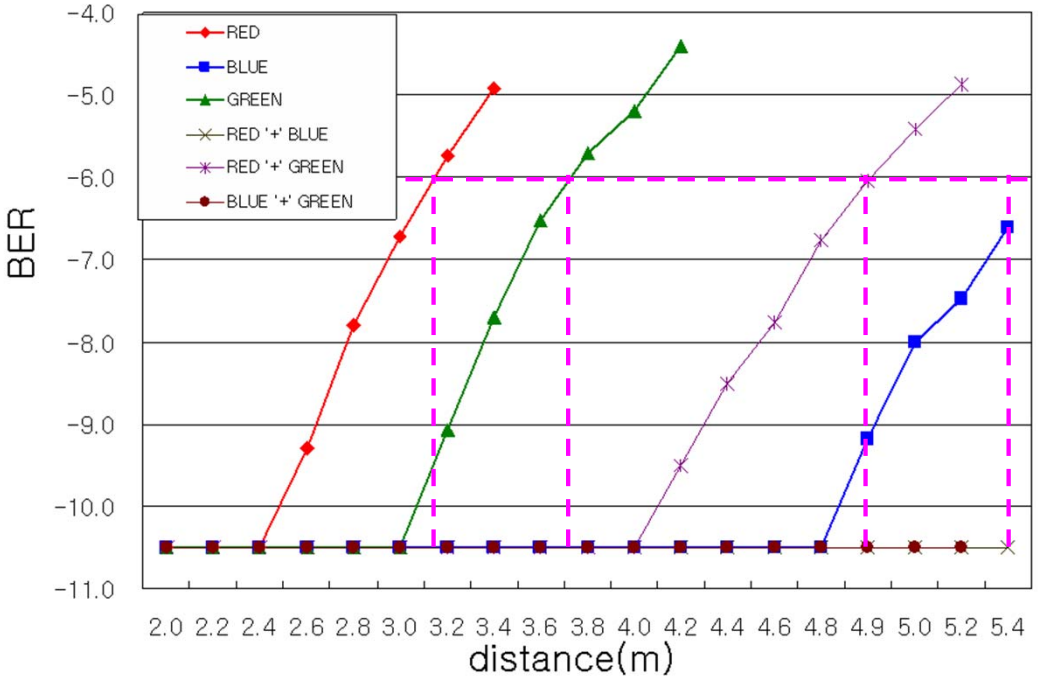
Transmitter (RGB Sign-Board)



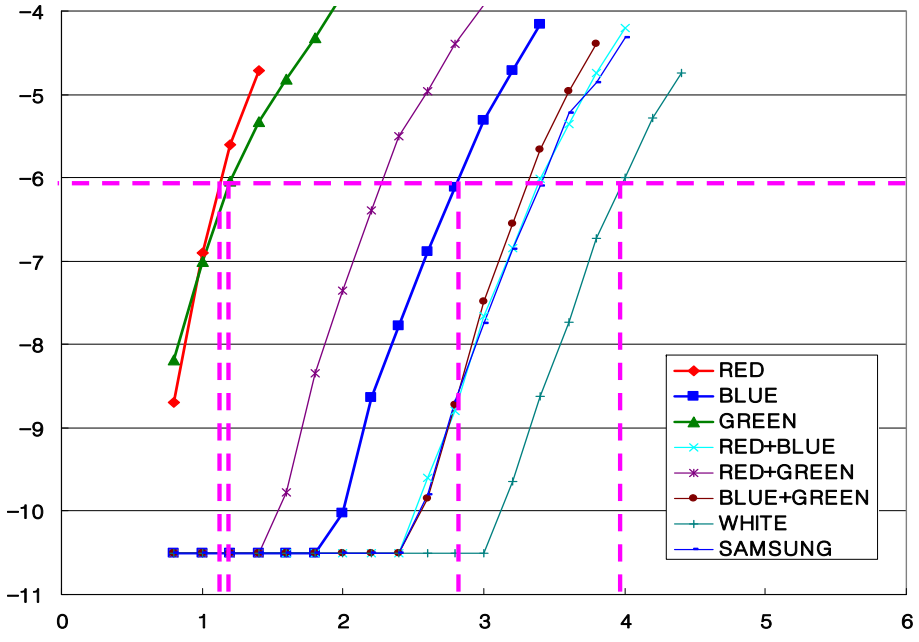
Receiver (Silicon PD)



Data Rate = 10 Mb/s

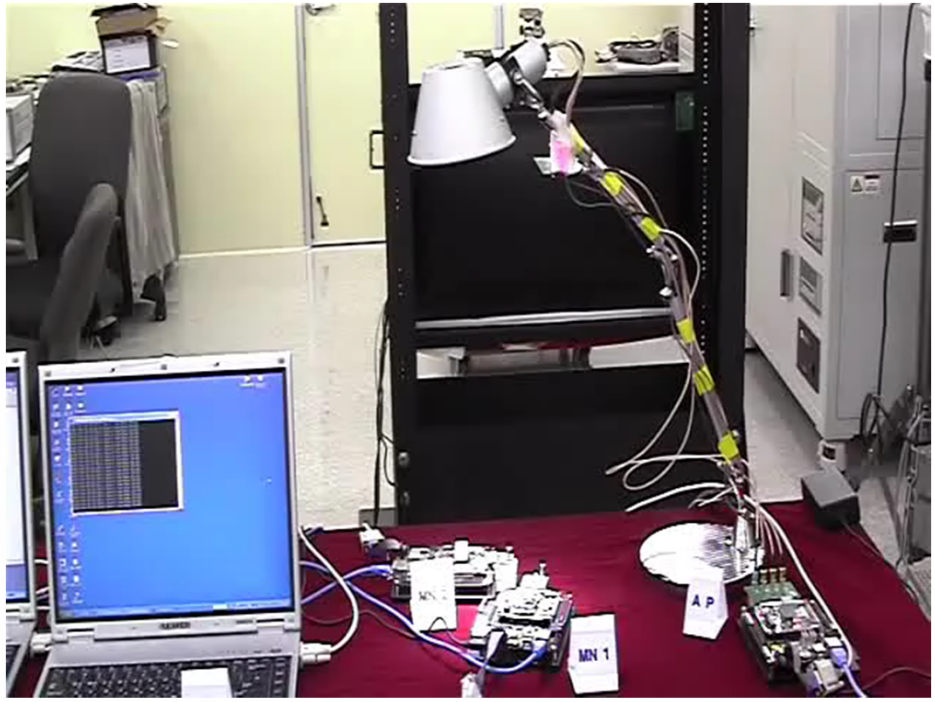


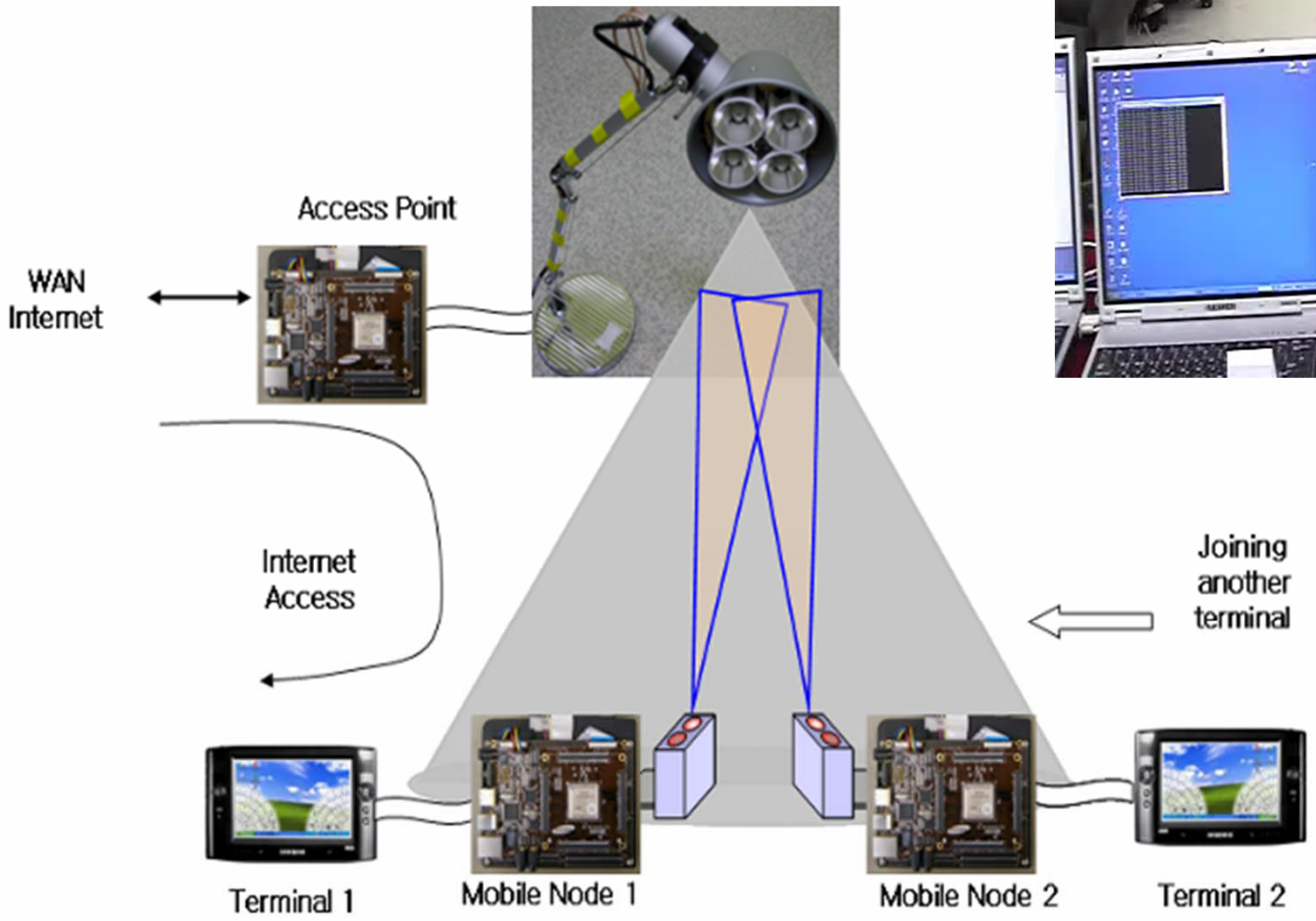
Data Rate = 20 Mb/s



Infra-to-mobile

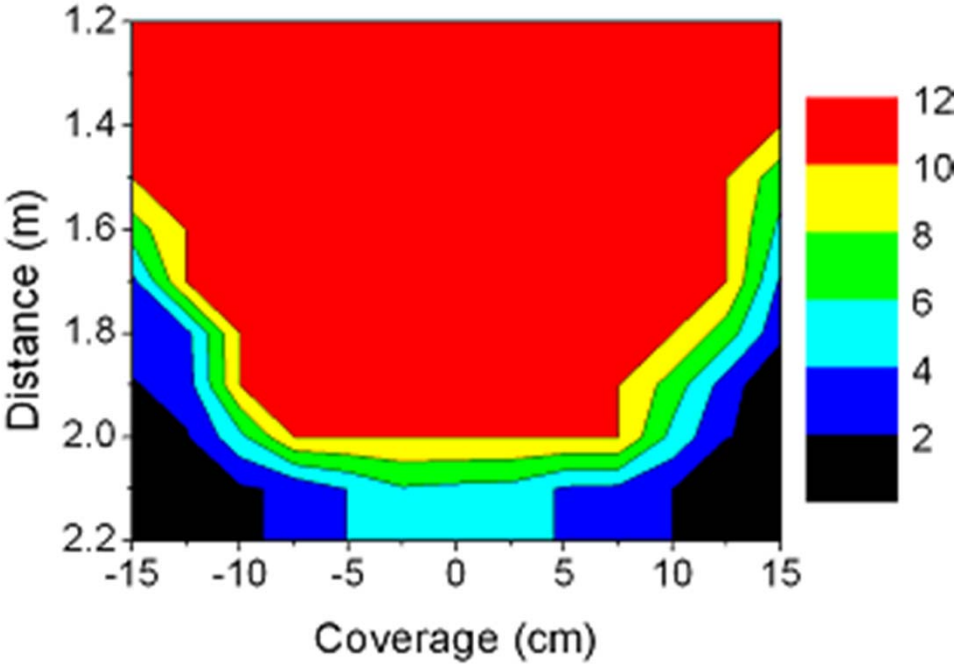
- TDMA-based P2MP
- 4 Mb/s, 3 m, bi-direction
- Secure indoor LAN



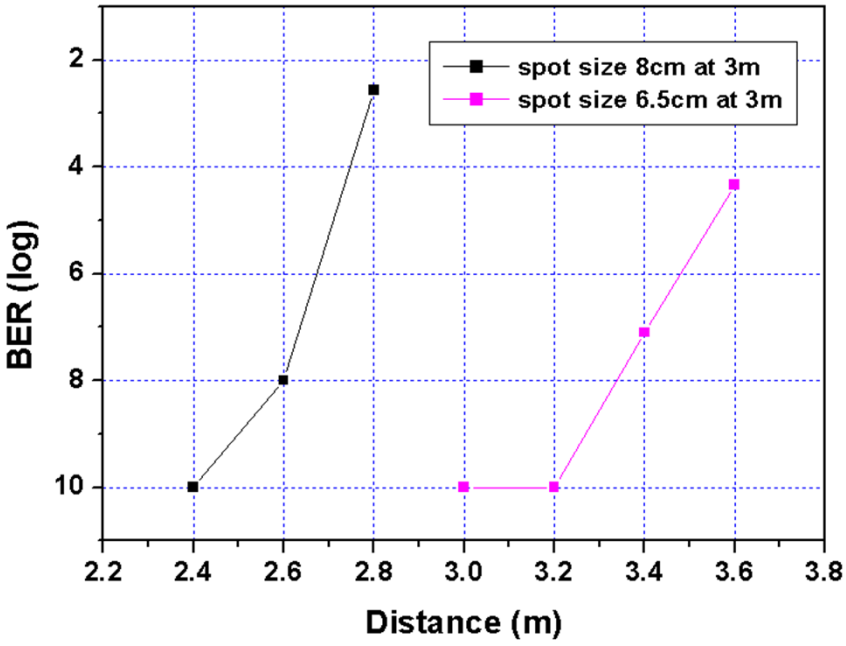


Infra-to-mobile (Link performance)

Downstream : White LED



Upstream : LD



Conclusion

- VLC is a communication technology that utilizes the visible light source as a signal transmitter, the air as a transmission medium, and the appropriate photodiode as a signal receiving component.
- Many advantages (e.g., security, health, eye safety, etc.) have driven the VLC technology to become more popular.
- VLC can be used in many applications.

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THANK YOU