

November 2008

doc.: IEEE 802.15-<08/0788-01>

Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Considerations on VLC Modulation]

Date Submitted: [12 November 2008]

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Abstract: [The considerations on the visible light communication (VLC) modulation are presented in this document.]

Purpose: [Contribution to IEEE 802.15 SG-VLC]

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Considerations on VLC Modulation

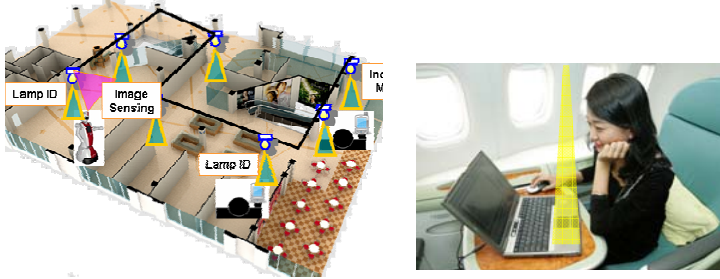
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Outline

- **Grouping of VLC applications**
- **Considerations of VLC PHY Modulation**
- **Details of Considerations**
 - **Illumination property, background noise reduction, high data rate, channel model etc.**
- **Summary**

Grouping of VLC Applications

		Application	Available Service	Major Functions
Machine To Machine	MD to MD	 <p>The other MDs, etc. MD #2 MD #3</p>	<ul style="list-style-type: none"> • Contents sharing • Multimedia transfer 	<ul style="list-style-type: none"> • High Data Rate Communication • Color-attractive for emphasizing visibility
	MD to FD	 <p>FD #1 FD #2 The other FDs, etc.</p>	<ul style="list-style-type: none"> • File transfer • Video streaming • Remote Control 	
Infra structure To MD/FD		 <p>Lamp ID Image Sensing Lamp ID Inc M</p>	<ul style="list-style-type: none"> • Indoor LBS • Information Broadcasting • Visible LAN 	<ul style="list-style-type: none"> • Lighting • Multiple Access

* MD : Mobile Device, FD : Fixed Device

Considerations of VLC PHY Modulation [1/4]

- Technical requirements for VLC PHY modulation
 - VLC modulation scheme for the purpose of applying to infrastructure shall **support the existing Illumination control function**.
 - Therefore, it needs to be discriminated from communication between mobile/fixed devices.
 - VLC modulation should consider **a direct baseband or subcarrier modulation** using optical sources such as LED or LD.
 - VLC modulation scheme should consider the **visibility** of the VL wavelength characteristic itself.

Considerations of VLC PHY Modulation [2/4]

- Technical requirements for VLC PHY modulation
 - VLC modulation scheme should **guarantee up to higher data rate (10kbps ~ 1Gbps) as application scenarios.**
 - The higher data rate should be satisfied in order to transmit enhanced multimedia data.
 - Environments for supporting data rate classes
: MD-to-MD, MD-to-FD, Infrastructure-to-MD/FD
 - VLC modulation scheme should **support background noise reduction.**
 - **The background noise** from external noises such as sunlight, illuminator, traffic signal etc. **should be avoided and excluded.**
 - VLC modulation should **consider the enhanced parallel transmission of RGB color or multiple wavelength.**

Considerations of VLC PHY Modulation [3/4]

- Technical requirements for VLC PHY modulation
 - VLC modulation scheme should **support signal distortion avoidance** in both Tx/Rx (LED/PD) and channel environment.
 - VLC modulation scheme should **consider the various channel models**.
 - In general, the VLC channel has almost a characteristic of LOS.
 - Here, multi-path distortion and adjacent channel interference should be minimized.

Considerations of VLC PHY Modulation [4/4]

- Technical requirements for VLC PHY modulation
 - VLC modulation scheme should **consider the bidirectional communication based on full and half duplex.**
 - **Wavelength reuse** should be supported for both full and half duplex.
 - Here, bidirectional use with single wavelength is possible.

Considerations as VLC Applications

- The required considerations can be discriminated as application environments.
 - The priority is as follows.

	Illumination Property	Background Noise Reduction	High Data Rate	Channel Model
Illumination Property				
Background Noise Reduction				
High Data Rate				
Channel Model				
Mobile to Mobile Device	V	V	VVV	Simple
Mobile to Fixed Device	V	V	VVV	Simple
Infrastructure	VVV	VVV	VV	complex

* **VVV** : certainly required , **VV** : very required , **V** : required , **X** : not required

1. Illumination Property

- Can be mainly used and considered in case of lighting communication using an LED.

(e.g. Indoor LBS, Information Broadcasting, and Visible LAN)

- In general, PWM method is used in order to adjust the brightness of LED lighting.
- But, the method may not be suitable for high speed communication.
- Also, the lighting function can not be ignored.
- In case of lighting communication by LED, PWM signal bandwidth higher than comm. signal bandwidth should be required to have a good signal performance .
- In other words, severe bandwidth waste
- New modulation method required

2. Background Noise Reduction

- **Can be mainly used and considered in case of lighting communication using LED.**
 - **Additionally external ambient optical noise with visible light spectrum band (380 ~ 780nm)**
(e.g. Sun light, Fluorescent and Incandescent lamp)
 - **Low noise characteristic (in photo detection)**
 - **Bad influence in direct baseband modulation of an LED**
 - **To enhance signal performance, the noise reduction or elimination is required.**
(e.g. subcarrier modulation : Data spectrum and noise spectrum can be divided.)

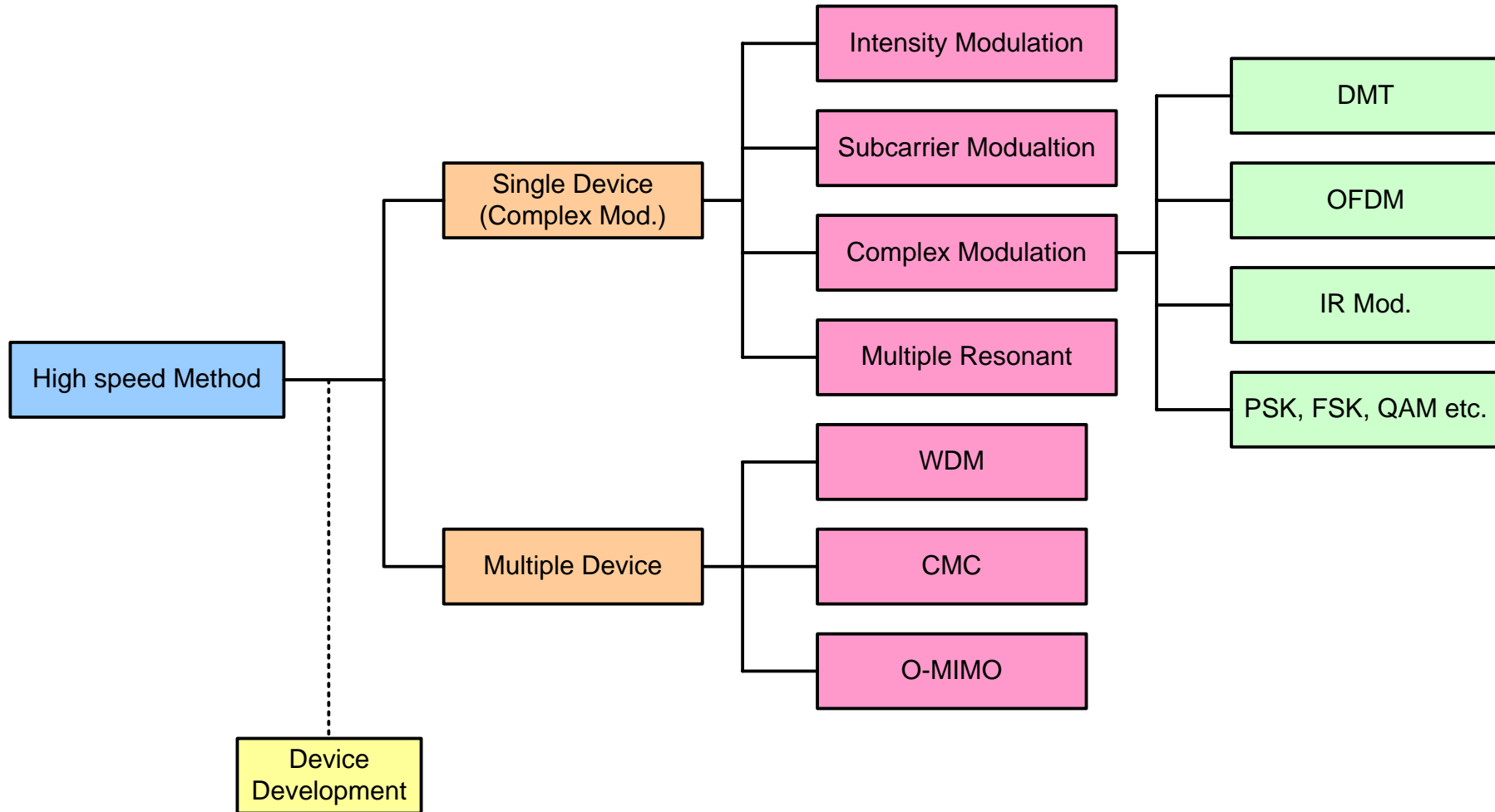
3. High Data Rate

- **Can be mainly used in peer to peer environment**

(Target : more than 1Gbps in about 1m range)

- **Single LED device based**
 - Intensity Modulation
 - Complex Modulation (Amplitude and Phase considered)
(e.g. PSK, QAM, or DMT, OFDM)
 - Multiple resonant circuit in low speed LED (Pre-equalization)
- **Multiple LED device based**
 - WDM Multiplexing method
 - Optical MIMO
 - Color Multiplexing Code

High Speed Modulation Categorization



4. Channel Model

- The visible light communication channel may be almost expected to LOS channel by various references until now.
 - MD-to-MD/FD
 - : Communication between portable or fixed devices
 - Short range peer-to-peer environment
 - (relatively little multipath/Interference distortion)
 - Infra-to-MD
 - : many interference can be existed.
 - New modulation method may be required.
 - Especially, the downlink of Infra-to-Mobile
 - Because, the beam divergence of downlink source is relatively wider.

Summary

- **VLC PHY modulation requirements**
 - Support general characteristics of visible light
 - A few different modulation approaches are required as each application.
 - Mobile-to-Mobile/Fixed devices (Between Devices)
 - Infra-to-Mobile/Fixed device
 - Here, illumination property, background noise reduction, high data rate, channel model characteristic etc. should be considered.
- For supporting requirements, P802.15 VLC should reflect the above when designing the VLC PHY.