Position: Health Effects in LED-based Communication Systems and Possible Mitigations

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ABSTRACT

With the invention of Blue LEDs (awarded with the Nobel Prize), white LEDs are now pervasively present in the market, and Visible Light Communication Systems (VLCS) are the result of intensive scientific investigations in the last years. In this work, we review the health effects of LED technology studied in vision science, implications of using VLC with LEDs, and new VLCS design considerations.

Introduction. Visible Light Communication System (VLCS) can provide very high data rate for high-end platforms and is a serious candidate for new use cases with low-end platforms such as sensing human motions, mobile interaction, and indoor localization. All this research exploits the pervasiveness of LEDs. In this work we review the potential health effects of LED technology, implications of using VLC with LED, and new VLCS design considerations.

In most of applications, VLCS maintains the primary goal of illumination, with embedded communication. As VLCS embeds information varying the intensity level of light, flicker can occur. Flickering is observed when the variation of illumination of a light source is noticeable to the human eye. This is a well-studied problem in fields like video games and visual displays, as well as older types of lamps. The energy that can be tollerated before flicker is proportional to $\exp(f^{1/2})$ ([4] and therein). In other words, the frequency at which human eyes do not observe any more flicker depends on the amount of photons at that frequency. At low frequencies, a relative low energy causes flicker and, at a higher frequencies, more energy is needed. While at low frequencies, flicker can merely distract the viewer, increasing the frequency, medical problems can occur such as photosensitive epilepsy [3]. Designed networking solutions must then prevent unwanted effects such as seizures and reducing eye strain so that flicker does not occur using visible light communication (some schemes are also introduced in the IEEE 802.15.7 standard [12]). In addition, as VLCS is a relative new field, methods that automatically compensate for flicker while experimenting PHY and MAC protocols should be considered.

Much less is known in the networking community about another health effect. With the invention of blue LEDs (awarded with the Nobel Prize [14]), white LEDs are now pervasively present in the market. Generating blue light was the "beginning of everything", a sort of genesis for the evolution that brought us to VLCS. Even more, medical studies have shown its positive effects on our ability to maintain a high level of attention during the day. However, the increased alertness caused by blue light comes at the drawbacks of higher stress, higher cardiac rhythm and reduced melatonin [1, 7]. The hormone melatonin (melanopic) is fundamental in explaining our wakefulness in the day and sleepness in the night, with production that goes up in the night in absence of blue light. Stress and bad sleep habits can quickly deteriorate the daily life.

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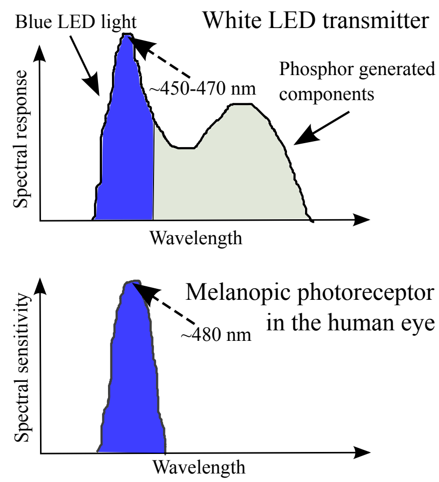

Figure 1: Top: LED spectrum, blue light components and phosphor-generated components. Bottom: spectral sensitivity of melanopic photoreceptor in the human eye.

Insights. As VLCS is a research area at the intersection of networking and optical communities, only harnessing optical propagation properties and alleviating its drawbacks can result in an impactful system. First, relevant VLCS metrics need to be taken into account to consider effects of VLCS modulation, and other transmission characteristics on human vision. Second, the choice of LED technology that is used for VLCS also can have an impact. In particular, what we call white LEDs is usually a luminary generated by a blue light source and a phosphor coating. The blue light impinges into the coating, and some blue photons generated in the LED travels through the phosphor layer without alteration, and others change their optical frequency components. Thus, photons from blue LEDs can downconvert their energy $E = \frac{hc}{\lambda}$ – where h is the Planck constant, c is the speed of light in vacuum and λ is the photon's wavelength – into green, yellow and red photons via phosphors [14]. As depicted at high level in Fig. 1, the result is a wide-band optical spectrum with two peaks in frequency, one of which is the blue LED light ($\lambda = 450 - 470$ nm) used as source, while the phosphor-dependent components have a peak that depends on the specific coating. The peak goes from $\lambda = 550$ nm (generating a cool white of color temperature up to 6500 K) to $\lambda = 650$ nm (generating a warm white of color temperature down to 2700 K) [2].

The white light that illuminates the environment reaches our melanopic photoreceptor, that has a spectral sensitivity with a peak around $\lambda = 480$ nm [11]. This matches closely the spectral response of the blue light emitted by white LEDs (cf. Fig. 1). The blue LED light is emitted regardless of the implemented modulation and networking access scheme, as long as the light is on. While a simple solution could be to dim the blue light, it will imply to proportionally reduce the illuminance level.

The question we want to pose is how VLCS relates to blue light, their mutual interaction and what means there are to reduce the health effects. We recall that data in VLCS is usually transmitted using intensity modulation, wherein, in its simplest formulation, binary information is mapped to the presence or absence of the visible light carrier. Intensity variation occurs at a relative high speed that depends on the application, for instance in the order of a few MHz. As the phosphor component is slow to react to intensity changes, typical methods to increase the baseband bandwidth are based on removing the phosphor-generated components at the receiver with a blue filter [10]. Hence, what is really used for communication is the blue light component of the white LED, that reaches the photodetector and is transformed into current. The consequence is that the blue light is currently essential not only to generate white LEDs for illuminating the environment, but also the key to achieve higher rate in data communication.

Possible directions. From the above discussion, ways to reduce the emission of blue light while preserving networking performance are necessary. Simply using LEDs with low color temperature (3000 K or less, ideal for night [7], with the peak due to the phosphor-dependent components in warm white not detected by the melanopic photoreceptor) is not a viable solution for LEDs that are used both for day and night indoor illumination. With the help of the optical community, new LEDs with controllable color temperature level and new coating solutions could be designed.

Another direction would be to investigate how VLCS technology can help out to optimize our exposure to blue light. A technological solution can be to move from the more and more pervasive blue LED+phosphor coating LEDs deployments to RGB (Red-Green-Blue) LEDs. The latter are capable of adjusting the single LEDs in the digital domain, and thus being effective against high exposure to blue light, preserving melatonin level, etc. However, RGB LEDs have achieved little penetration in the market due to their higher cost. As of today, their cost is high as they require a more complex control circuit to create white light, and ways to reduce their cost is needed. We look next how VLCS can help.

Some initial help may come from the fact the RGB LEDs can allow us to achieve higher communication rate, also when the intended receiver is the smartphone's camera, as a result of the fact that there are three independent communication channels [6]. Another help may come from the fact that, inverting the bias of LEDs, they work similarly to photodetectors and they can transform the impinging light into photocurrent. This area of research is called LED-to-LED communication networks it uses low-power LED indicators and it has found applications for low-end systems [5]. Ideally, these concepts could be applied to white LEDs, so that they can be communicate between themselves, as an alternative to powerline. However, the problem of blue+coating white LEDs is that, once reverse biased, the coating itself blocks the reception of photons in the visible spectrum. Thus white LEDs require a photodetector to communicate with other white LEDs [13]. The opposite holds with RGB LEDs, that do not have any special coating. The red, green and blue LED of RGB LEDs can receive light in an optical spectrum close to the emitting spectrum of each respective LED (e.g. red LED can receive red light), with the additional property that the blue LED can also receive light in the ultraviolet frequency and thus detect the presence of sun light [8, 9]. Re-using the RBG LEDs both for receiving data and adjust the ambient light is then feasible. This enables RGB LED-to-RGB LED communication with ambient light control, and it avoids the usage of dedicated photodetectors (one for communication and one to detect ultraviolet light to measure the sun light) for this purpose. The cost saved can become compelling and lower the overall cost of RGB LEDs with respect to blue+phosphor coating LEDs + photodetectors.

Once RGB LEDs have largely penetrated in the market, modulation schemes for communication can be carefully designed considering as baseline the Color Shift Keying (CSK) modulation [6], and adapting the blue component according to measured day and night time conditions as well as external sun light presence, with higher levels during the day (to help focusing if no sufficient external natural blue light from the sun is present) and lower levels during night (to avoid health effects).

REFERENCES

[1] Health effects of artificial light. In *Scientific Committee on Emerging and Newly Identified Health Risks* (March 2012).

[2] Chen, D.-C., Song, Z., Liu, Z.-G., Deng, Z.-H., Wu, L., Cao, Y.-G., and Liu, Q.-L. Peak wavelength selection guides of chip and phosphors for phosphor-converted white light-emitting diodes. *Rare Metals 33*, 1 (2014), 80–85.

[3] da Silva, A. M., and Leal, B. Photosensitivity and epilepsy: Current concepts and perspectives- a narrative review. *Seizure* (2017).

[4] Farrell, J. E. An analytical method for predicting perceived flicker. *Behaviour & Information Technology 5*, 4 (1986), 349–358.

[5] Giustiniano, D., Tippenhauer, N. O., and Mangold, S. Low-complexity visible light networking with led-to-led communication. In *2012 IFIP Wireless Days* (Nov 2012), pp. 1–8.

[6] Hu, P., Pathak, P. H., Feng, X., Fu, H., and Mohapatra, P. Colorbars: Increasing data rate of led-to-camera communication using color shift keying. In *ACM CoNEXT '15* (New York, NY, USA, 2015), ACM, pp. 12:1–12:13.

[7] Kraus, L. J. Human and environmental effects of light emitting diode (led) community lighting. In *CSAPH Report 2-A-16* (June 2016).

[8] Li, S., and Pandharipande, A. Led-based color sensing and control. *IEEE Sensors Journal 15*, 11 (Nov 2015), 6116–6124.

[9] Li, S., Pandharipande, A., and Willems, F. M. J. Daylight sensing led lighting system. *IEEE Sensors Journal 16*, 9 (May 2016), 3216–3223.

[10] O'Brien, D. C., Zeng, L., Le-Minh, H., Faulkner, G., Walewski, J. W., and Randel, S. Visible light communications: Challenges and possibilities. In *IEEE PIMRC 2008* (Sept 2008), pp. 1–5.

[11] Price, L. Report on the first international workshop on circadian and neurophysiological photometry, 2013. *Int Comm Illum* (2015), 2015.

[12] Roberts, R. D., Rajagopal, S., and Lim, S. K. Ieee 802.15.7 physical layer summary. In *2011 IEEE GLOBECOM Workshops* (Dec 2011), pp. 772–776.

[13] Schmid, S., Richner, T., Mangold, S., and Gross, T. R. Enlighting: An indoor visible light communication system based on networked light bulbs. In *Sensing, Communication, and Networking (SECON), 2016 13th Annual IEEE International Conference on* (2016), IEEE, pp. 1–9.

[14] Tsao, J. Y., Han, J., Haitz, R. H., and Pattison, P. M. The blue led nobel prize: Historical context, current scientific understanding, human benefit. *Annalen der Physik 527*, 5-6 (2015).