Is There a Place for VLC in Wireless Sensor Networks?

Niranjini Rajagopal Patrick Lazik Anthony Rowe
Electrical and Computer Engineering Department
Carnegie Mellon University
{niranjir, plazik, agr}@ece.cmu.edu

ABSTRACT

This paper explores the possible services and their associated challenges that Visible Light Communication (VLC) can provide to a Wireless Sensor Network (WSN). We believe VLC has the potential to improve services such as localization, time-synchronization, low-power wakeup and batch-programming of sensor nodes. With the proliferation of both large-scale indoor sensing systems and VLC-enabled lighting systems, we outline various scenarios where VLC can compliment WSNs.

1. MOTIVATION - VLC CHARACTERISTICS

One of the main drawbacks of VLC is that lights typically only provide a one-way data downlink. Despite this limitation, there are several applications which can benefit from incorporating VLC as a side channel. In this paper, we explore VLC in the context of WSNs.

1.1 Power-Line Back-End

By their nature, lights are wired, making them ideal for Power Line Communication (PLC). The power-line layout in buildings is usually static and propagation time of signals through the power-line network is constant with low jitter. VLC can provide a link between the power-line and nearby sensor nodes.

1.2 Spatial Diversity and Structured Layout

The layout of overhead lights is typically fairly regular, symmetric and well spaced out. This makes them prime candidates for anchors of localization systems. One of the main drawbacks of anchor-based localization systems is the time intensive calibration process of determining the anchor positions. The structured layout of lights can drastically reduce this complexity, and help determine accurate anchor positions. Lights are also typically located in the center of spaces.

1.3 High Transmit Power

The transmit power of lights under typical illumination is high enough for low-power embedded tags to detect them, making them suitable for one-way communication with these tags.

1.4 High Data Rate

The high rate communication possible with high bandwidth, unregulated spectrum makes lights a good candidate for fast downlinks. This could be used for batch programming of sensor nodes.

2. VLC SERVICES

Given the unique properties of VLC, we believe it can improve the following WSN functions:

2.1 Localization

Knowledge of the position of sensors is important for many WSN applications. Due to the high degree of spatial confinement of light, VLC can help uniquely identify a nearby device by using the lights as landmarks [?]. In case of sensor nodes, the localization requirement could simply mean determining the proximity of certain nodes. Using approaches such as modeling parameters such as angle of illumination and distance from the light, VLC-based localization systems have achieved sub-meter accuracy with as few as one transmitter per room [?], [?]. The trade-off in most of these systems is between the level of localization accuracy, complexity, number of lights in view and additional hardware on the receiver.

2.2 Time Synchronization

Existing lighting infrastructure may be used to synchronize devices using broadcasts from a low jitter source. Traditional approaches rely on using radio links, which are limited in range or require more complex multi-hop protocols to provide precise synchronization over a large area. By leveraging the existing power line infrastructure connected to VLC bulbs, time synchronization packets may be broadcast using PLC, which would then be forwarded over VLC to receiving sensor nodes. In many commercial buildings, lighting power is distributed on a separate higher-voltage circuit with less appliance noise. The 60Hz AC power signal may also be used to provided coarse synchronization between the bulbs.

2.3 Low-Power Wakeup

Low-power sensor nodes often rely on schedules or techniques such as Low-Power Listening (LPL) to wake up and receive or transmit packets over their radio. Since powering up the node's radio and processor consumes a significant amount of energy, an alternate, lower power wireless signaling technique would drastically reduce energy requirements. By using a photodiode circuit [?] to trigger an interrupt on sensor nodes, a VLC channel may be used to asynchronously wake-up nodes exactly when they need to communicate. Techniques such as Frequency Division Multiple Access (FDMA) may be employed to create multiple channels for waking up individual nodes.

A VLC based low-power wakeup signal may also be used to indicate that the wireless sensor network is online, eliminating the routine sampling of radio channels. One could imagine this has implications in transporting sealed devices and waking them up upon installation.

2.4 Secure Batch Programming

Sensor network deployments often require firmware updates throughout their lifetime. Programming all nodes individually can quickly become a difficult task depending on the installation size. Using RF to reprogram nodes also poses security problems since data can be easily eavesdropped. VLC may alleviate this problem by allowing batch programming of sensor nodes over widespread lighting infrastructure. Visible light provides a "what you see is what you get" communication channel that is easier to confine and secure.

3. CHALLENGES

Though VLC has a great potential to provide these services to WSN, there are many open challenges.

3.1 Standards for Co-Existence of Services

VLC Standards such as 802.15.7 currently have to take into account illumination requirements as part of the communication protocols. If the lights provide additional services, we need to think about how these services can co-exist without compromising the primary function of the light. Another important consideration is the impact of these additional services on the energy-efficiency of the lighting system.

3.2 Designing Efficient Transmitters and Receivers

While many LED bulb designs exist, some of which already feature microcontroller based PWM control of the LED elements as well as wireless communication over 802.11 or 802.15.4, additional hardware and software will be required for power line communication, time synchronization and data modulation. Bandwidth limitations may further complicate the transmission of VLC signals. Transmission schemes need to be designed in an extremely lightweight manner to ensure that lights are still economical.

On the receiving side, low-power hardware needs to be designed which consumes significantly less power than radio based solutions. These receivers need to function over a wide range of lighting intensities so as to allow free placement of sensor nodes in the environment.

3.3 Multiple Access

In a VLC ecosystem, multiple lights transmit and multiple sensor nodes listen on the same medium. In order for systems to scale, multiple access support needs to provide fair communication and Quality-of-Service.

3.4 Rate-Adaptive Communication

Typically two-way communication channels determine operating rates through a bi-directional negotiation. In VLC systems, this information would need to be shared using an auxiliary uplink (like RF).

4. CONCLUSION

The main focus in the VLC research community is on high-data rate communication. However, this is only part of VLC's potential. The fact that lights are powered, unregulated and ubiquitous is key to enabling services that are challenging with RF-only solutions. Currently, VLC is in a state where it can improve many attributes of wireless systems, but doesn't dominate any one single domain. Is there space for VLC in Wireless Sensor Networks? Maybe. We hope to see a more holistic view of the communication ecosystems where WiFi, PLC and VLC are combined. We believe that the whole would be greater then the sum of each part.

5. REFERENCES

[1] N. Rajagopal, P. Lazik, and A Rowe. Visual light landmarks for mobile devices. In *Proceedings of the 13th ACM/IEEE Conference on Information Processing on Sensor Networks*, 2014.

[2] Y. Kuo, P. Pannuto, K. Hsiao, and P. Dutta. Luxapose: Indoor positioning with mobile phones and visible light. In *Proceedings of the 20th International Conference on Mobile Computing and Networking*, 2014.

[3] Liqun Li, Pan Hu, Chunyi Peng, Guobin Shen, and Feng Zhao. Epsilon: A visible light based positioning system. In *11th USENIX Symposium on Networked Systems Design and Implementation (NSDI 14)*, pages 331–343, Seattle, WA, April 2014. USENIX Association.

[4] N. Rajagopal, P. Lazik, and A Rowe. Hybrid visual light communication for camera and low-power embedded devices. In *Proceedings of the 1st ACM Workshop on Visible Light Communication Systems*, 2014.