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

Submission Title: Amplitude Modulated VLC Dimming Challenges
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Re:

Abstract:

Purpose:

Summary

This presentation pertains to PHY 1 and PHY 2 type devices and the challenges that dimming poses. In this presentation we'll discuss:

1. While 802.15.7 must honor all dimming requests, it is not possible to support useful data communications under all dimming conditions.

2. The useful bit rate is dimming related; that is, for different dimming requirements the minimum bit rate varies.

3. The un-resolved issue is " if the minimum bit rate is dimming dependent, then what bit rate shall be used for link establishment?"

Assumptions

In regards to PHY 1 and PHY 2 … dimming is challenging and problematic.

Assumptions in this presentation:

1. During amplitude modulation the LED is either ON or OFF

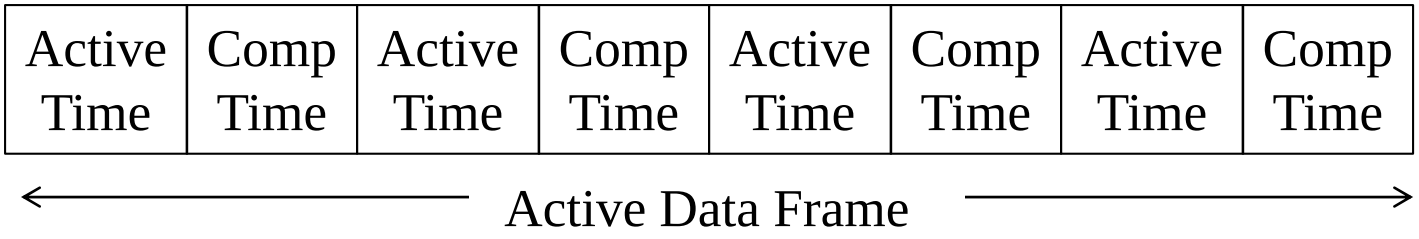
2. The optical rate is so high that intra-frame flicker is not a problem

Terminology interpretation:

1. Intra-frame flicker has two possible causes *(need to modify definition)*

a) Optical rate (which we assumed is very high – so not a problem)

b) Frame modification to accommodate dimming (potential problem)



2. Inter-frame flicker is the flicker between frames

a) Requires compensation transmission between frames (no problem)

Dimming impacts performance three ways:

1. Causes data rate reduction in OOK and range reduction in VPM.

2. Can cause dimming related intra-frame flicker in OOK and link reliability problems in VPM.

3. Given a minimum size link establishment packet and a practical dimming limit, a minimum data rate restriction is imposed.

We now qualitatively expound on these three points in the following slides.

Point #1 – impact of dimming on data rate and range

As the LED dims, the energy available for amplitude modulated data transmission has to decrease.

OOK impact: constant range with reduced data rate

• OOK sends data with either the LED full-on or full-off (stated assumption), so if the energy per bit stays constant then the data rate must be reduced (because of less available energy)

• This is manifested in the fact that to achieve dimming with OOK, intra-frame dead time must be inserted

VPM impact: constant data rate with reduced range

• As the light dims, VPM continues to send data at the same rate but with less energy per bit; hence, the range must be reduced

Point #1 – impact of dimming on data rate and range (continued)

Impact of using OOK for link establishment and then switching to "dimmed VPM" for packet data transmission

According to the draft, VPM does link establishment using OOK (50% duty cycle VPM) and then switches to "dimmed VPM" (less than 50% duty cycle) for the packet body.

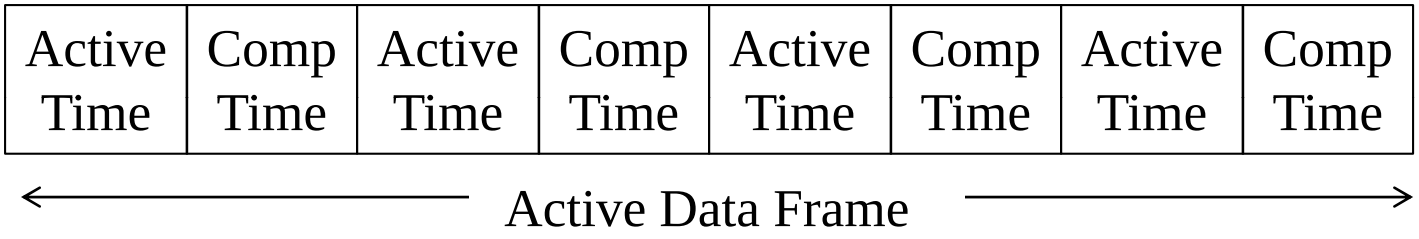
• Dead time is inserted between the OOK transmission and the VPM transmission to compensate for the OOK part of the frame

OOK Link Establishment	Comp Time	VPM Data Body

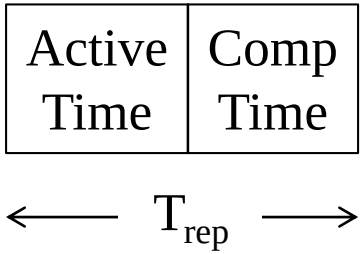
• Also, ***the link can be established at longer range than the packet body can be transmitted***. This will result in being able to connect but not being able to pass data.

Point #2 - dimming related intra-frame flicker in OOK

Intra-frame dimming in OOK is achieved by the insertion of compensation time into the active frame.



If the repetition rate of the active and comp time becomes too low then flicker can start to occur



Point #2 - dimming related intra-frame flicker in OOK (cont.)

The minimum active time is determined by a null packet (no data body, as shown below)

PHY Preamble (124 bits)	PHY Header (40 bits)	MAC Header (40 bits)

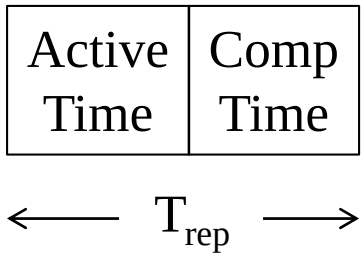
PHY rates and corresponding active times for null packet:

5 kbps ➔ 40.8 msec

50 kbps ➔ 4.08 msec

100 kbps ➔ 2.04 msec

Point #2 - dimming related intra-frame flicker in OOK (cont.)

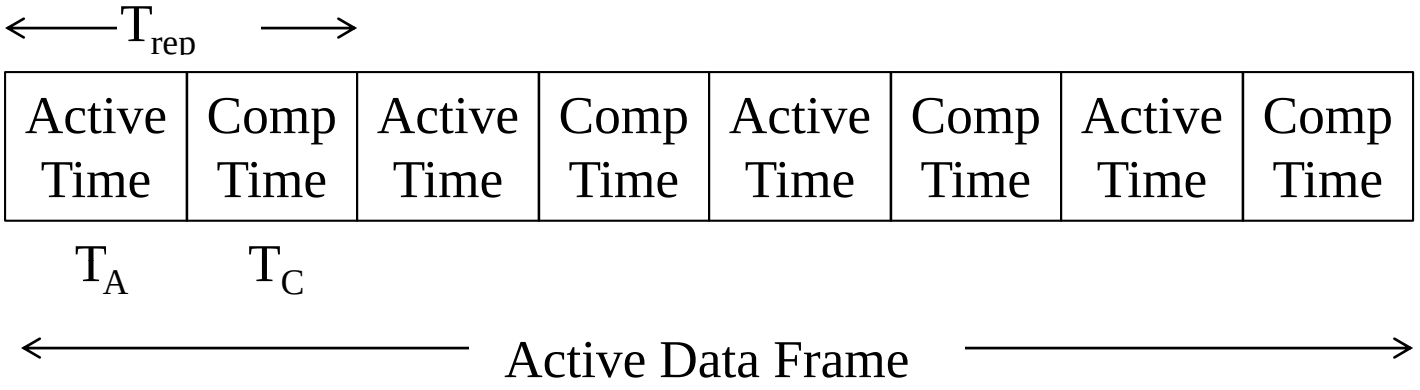


The amount of required comp time is determined by three factors:

1. Number of bytes (bits) in a null packet (minimum length packet)
2. The bit rate used to transmit the null packet
3. The actual dimming required (i.e. necessary duty cycle)

The fact is - given any null packet length and reasonable bit rate, we can always find an extreme dimming requirement that will result in flicker; that is, in theory it is not possible to avoid intra-frame flicker due to dimming UNLESS we pragmatically state that at some degree of dimming we NO LONGER ATTEMPT data communications!

Point #3 - Given a minimum size link establishment packet and a practical dimming limit, a minimum data rate restriction is imposed



$$\text{If } T_c>0 \text{ then } T_{rep} = T_A+T_C <= T_{flicker}$$

$$T_C = T_A \text{ x } K_{dim} \text{ where } K_{dim} \text{ is the required dimming constant}$$

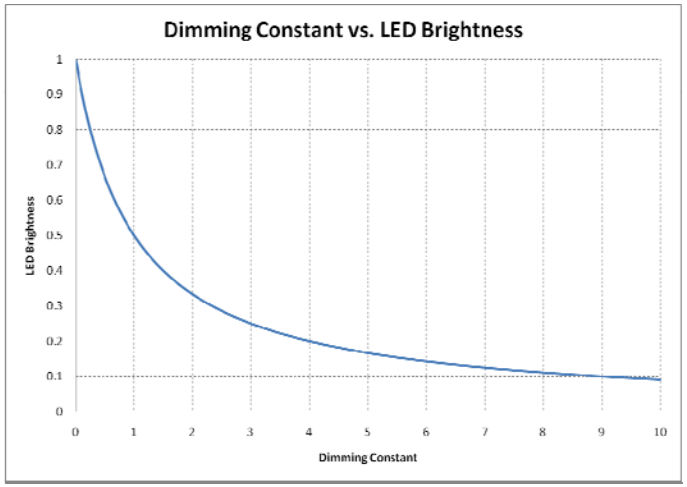
$$T_A = L_{bits\ min} \text{ x } T_{rate} \text{ where } T_{rate} = 1/(\text{data rate})$$

$$\text{Solving for } T_{rate} \text{ in terms of constants: } T_{rate} \leq T_{flicker} / \{(1+ K_{dim})L_{bits\ min} \}$$

Point #3 - Given a minimum size link establishment packet and a practical dimming limit, a minimum data rate restriction is imposed (cont.)

So for a given dimming constant and minimum length "null packet", there is a minimum bit rate that can be used and still avoid flicker.

If $T_c>0$ then $T_{rate} \leq T_{flicker} / \{(1+ K_{dim})L_{bits\ min}\}$



If no constraints are placed on the dimming constant then in theory the minimum data rate, to avoid flicker, is unconstrained.

The question is "what to do about this"?

The authors suggested way forward is two fold:

1. For PHY TYPE 1 … for link establishment, OOK and VPM use different bit rates according to the modulation type.

Table 2—PHY Type 1 Operating Modes

	Modulation	RLL code	Optical rate	FEC	Data rate
PHY I	OOK	Manchester	200 kHz	~~RS(15,3)+1/4CC~~	~~5 kbps~~
				RS(15,7)+1/4CC	11.67 kbps
				RS(15,11)+1/3CC	24.44 kbps
				RS(15,11)+2/3CC	48.89 kbps
				RS(15,11)	73.3 kbps
				1	100 kbps
	VPM	4B6B	400 kHz	RS(15,2)	35.56 kbps
				RS(15,4)	71.11 kbps
				RS(15,7)	124.4 kbps
				1	266.6 kbps

Delete – too slow

Use for OOK *LE*

Use for VPM *LE*

LE means Link Establishment

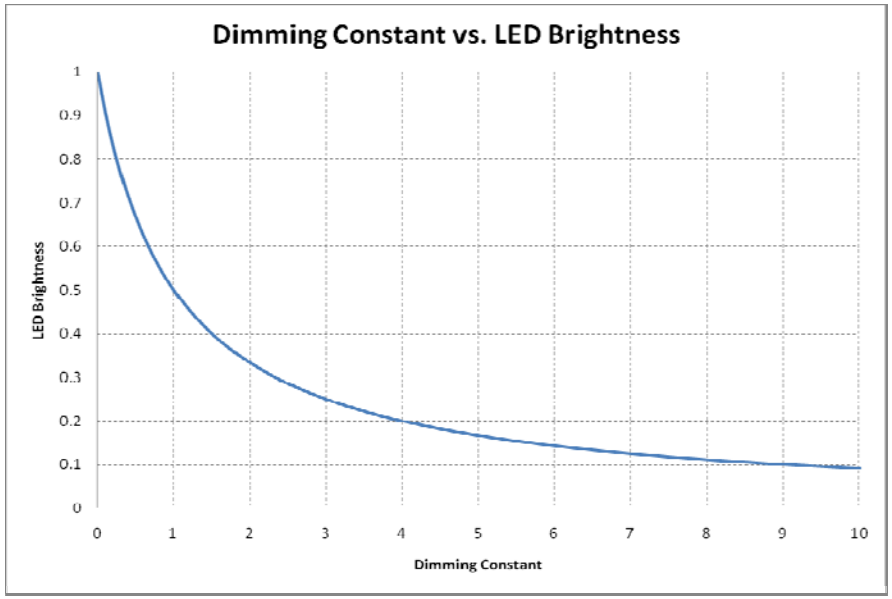
2. All PHY types must support dimming down to 0.1% (as currently in the draft) BUT the transmission of data under any given dimming condition is an implementation option.

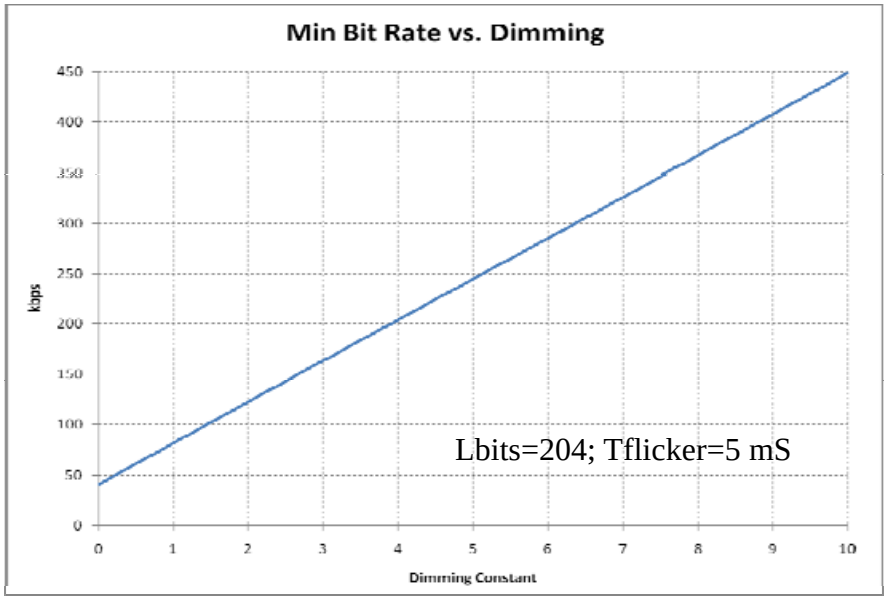
To clarify, a device can decide to no longer support data transmission for an arbitrary level of dimming. To do this the device simply no longer participates in the link establishment.

If a problematic amount of dimming is requested during a data transmission session, the device can issue a “stopping transmission due to dimming” command and then go off the air. *This command would have to be added to the draft.*

Backup Slides

Calculated Bit Rates vs. Dimming





The missing data is related to the link budget: what does the **Range vs. Data Rate** curve look like (specifically for the auto use case)? I fear the standard is getting out in front of the science!