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

Submission Title: Toward higher data rates
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Re: N/A

Abstract: Overview of avenues for achieving higher data rates. The ideas presented are complementary to the strategies chosen in the VLC base-line draft.

Purpose: Helping TG 802.15.7 to shape the use-case scope of a VLC standard

Toward higher data rates

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Motivation for this contribution

- 3+ years track record in high-speed VLC
- Provide our thoughts on achieving higher data rates (with an emphasis on lighting scenarios)
- Ideas presented complement avenues in base-line draft (15-09-0786-01-0007)
- Smorgasbord: You pick and chose (or don't pick at all)
- Upon request we happily provide more details on chosen topics

Outline

- Now or later?
- Higher data rates through exploitation of
  - Spatial diversity
  - Colour diversity
  - High SNR
- Summary and Conclusions
- References
- Acknowledgment

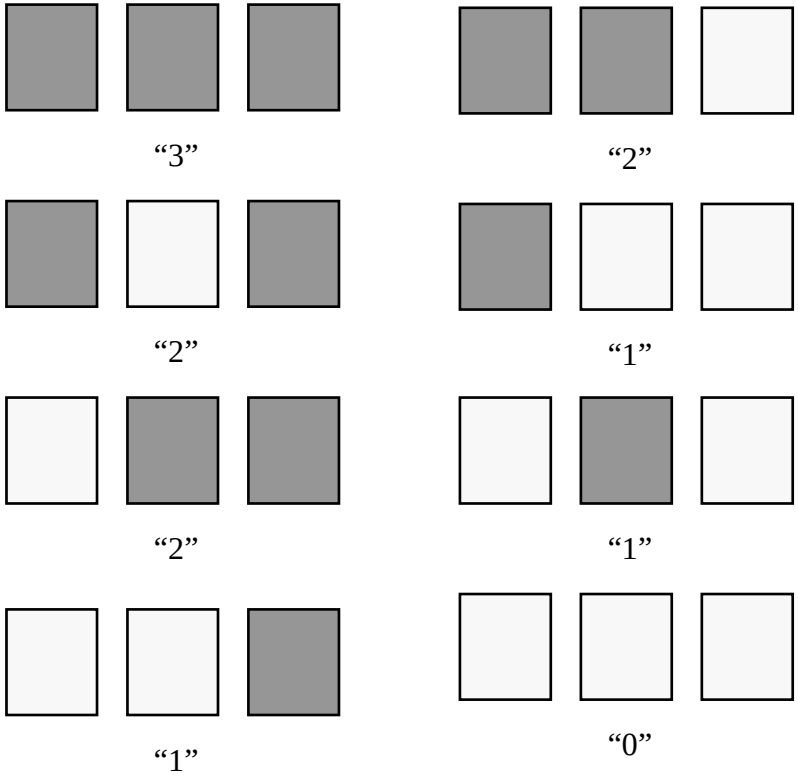
Now or later?

- Relevant for current base-line draft or follow up?
- Reality: Up to draft sponsors
- However: If interest to integrate (some of) ideas presented in extension of IEEE 802.15.7 ensure that current standard does not bar future extensions

Exploiting spatial diversity

Principle:

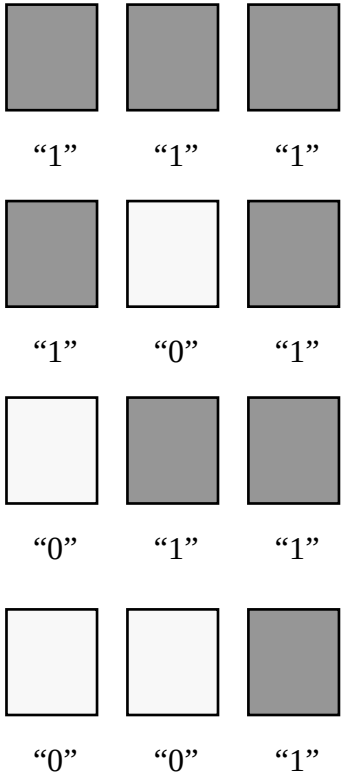
- Array of LEDs that can be individually modulated
- Zero-dimensional detector
- Total radiant LED power equals symbol value; need 2^n emitters for *n* bits per symbol
- Random selection of configuration for intermediary symbol levels ensures illumination uniformity
- Choose “max value” → brighter and “0” dimmer (or vice versa). Other binary modulation formats work too, e.g. VPM
- Power-averaged idle sequence, e.g. “30”
- One-dimensional or two-dimensional receiver → *n* emitters for *n* bits per symbol

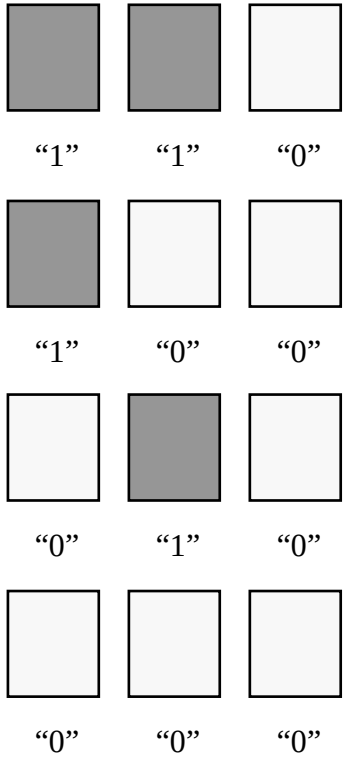


Exploiting spatial diversity, contd.

Advantages:

- Very simple driving circuit (on and off)
- Can be combined with Manchester coding (low data rate), VPM (earlier – later), and CCM (each tile an RGB diode)
- Higher data rates for same bandwidth with single-colour LEDs





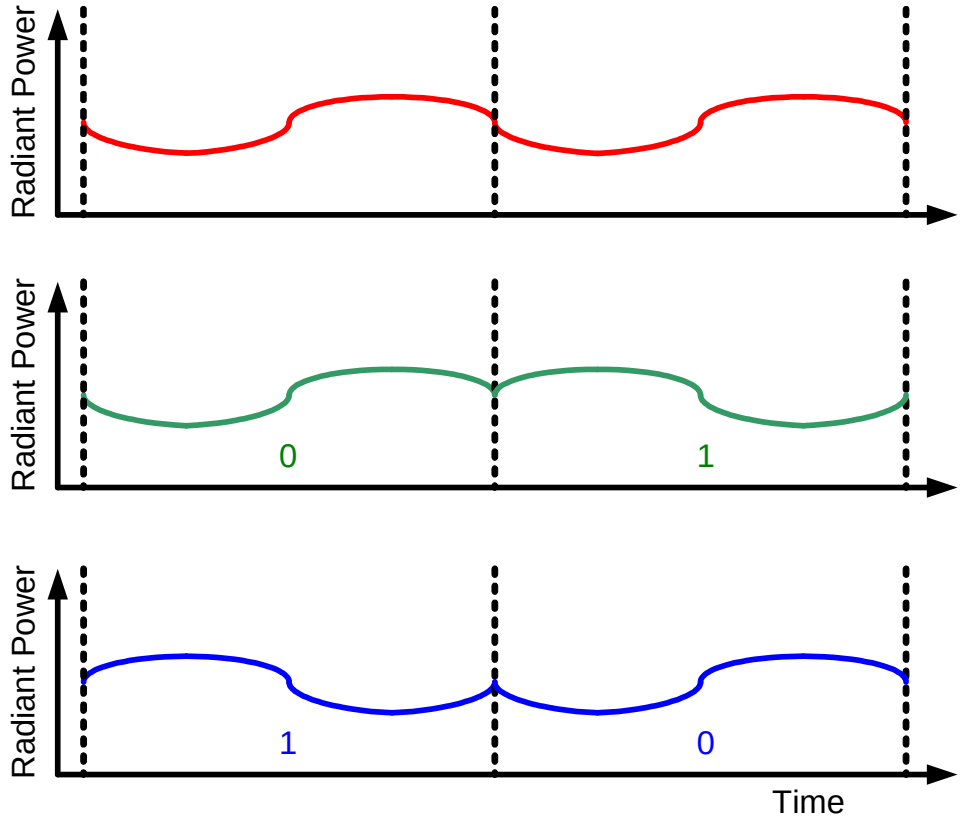
Exploiting colour diversity

Principle:

- CCM: Intensity of each elementary colour contributes to symbol
- Additional freedom: phase relationship between colours (at least two more bits per sent CCM symbol)

Implementation example

- BPSK on sub-carrier for white constellation point

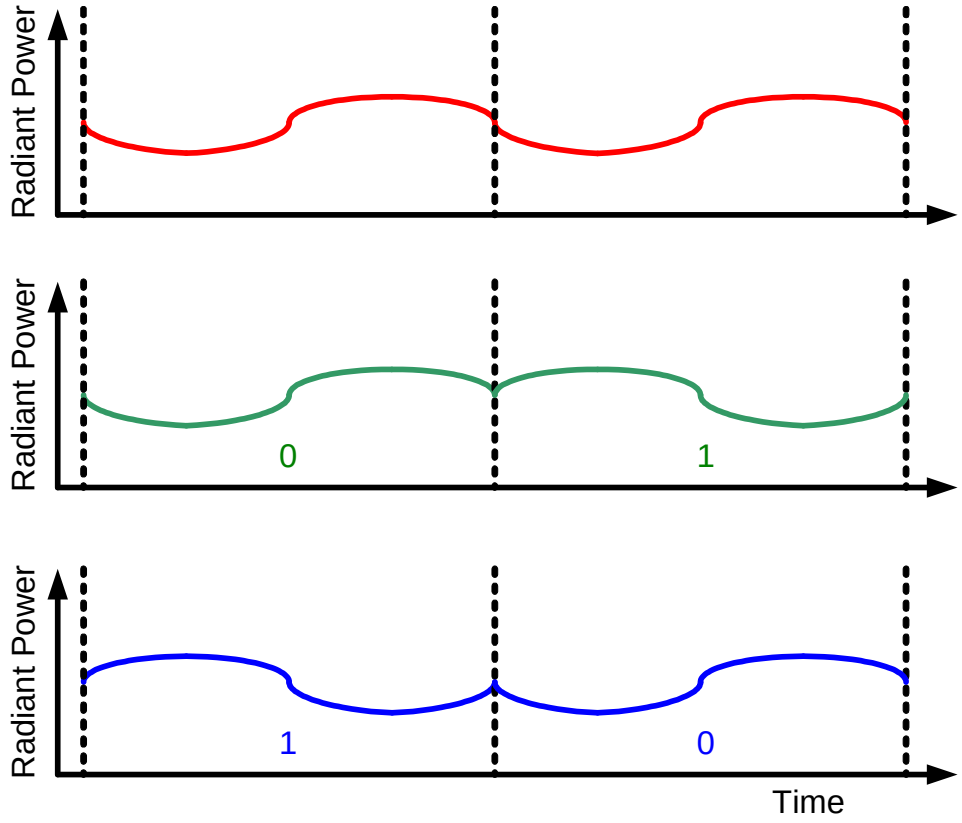


Aggregate data stream:
0110

Exploiting colour diversity, contd.

Benefits etc.

- PSK on all carriers possible (at least three extra bits per cycle), but with our approach clock recovery very simple (here: red)
- Phase-shift symbols "orthogonal" to CCM symbols → support of two independent data streams (e.g., "payload" and control data)
- Con: need linear driving circuit. Pro: already at hand (CCM!)



Aggregate data stream:
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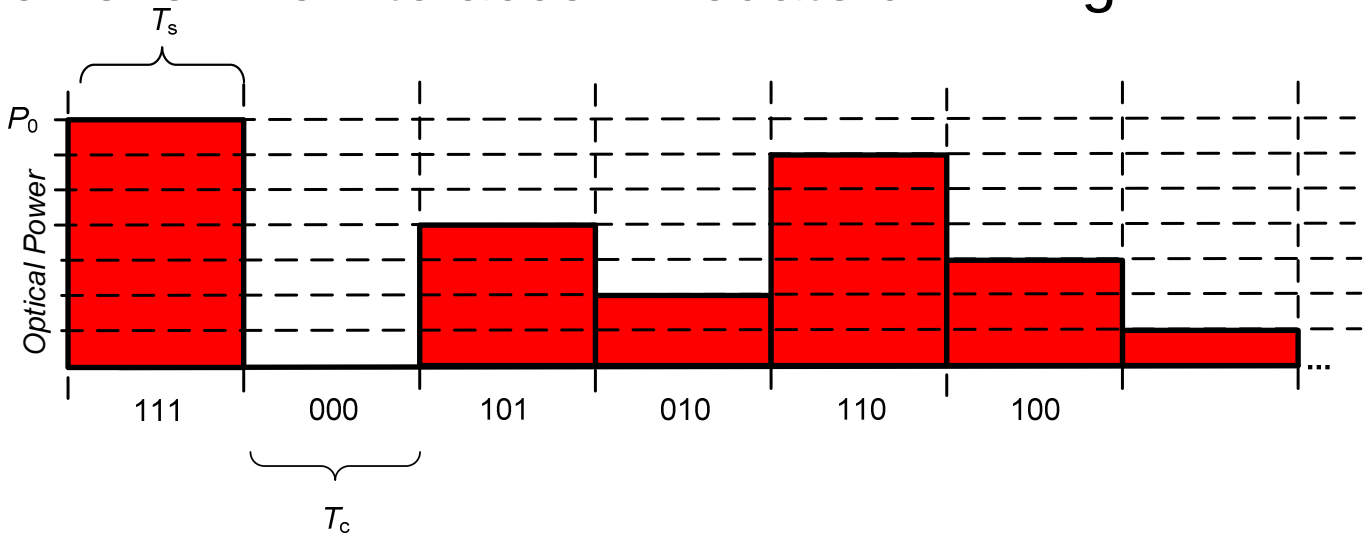
Exploiting prevalent high SNRs

- SNRs in lighting scenarios very high, e.g. ~ 58 dB for [Grubor, 2008]
  - 400 lx
  - phoshporescent LEDs
  - blue-filtered detection
  - 20 MHz modulation bandwidth
- What about PWM dimming?
  - Only duty-cycle variation, not peak amplitude
  - Thus: same high SNR during “on” state
- What about single-colour or phosphorescent white LEDs when it comes to high data rates?
- Suggested strategy: several bits per symbol. How?
  - Adaptive multi-level pulse-amplitude modulation (PAM)
  - Symbol-length coding

Exploiting prevalent high SNRs: multi-level PAM

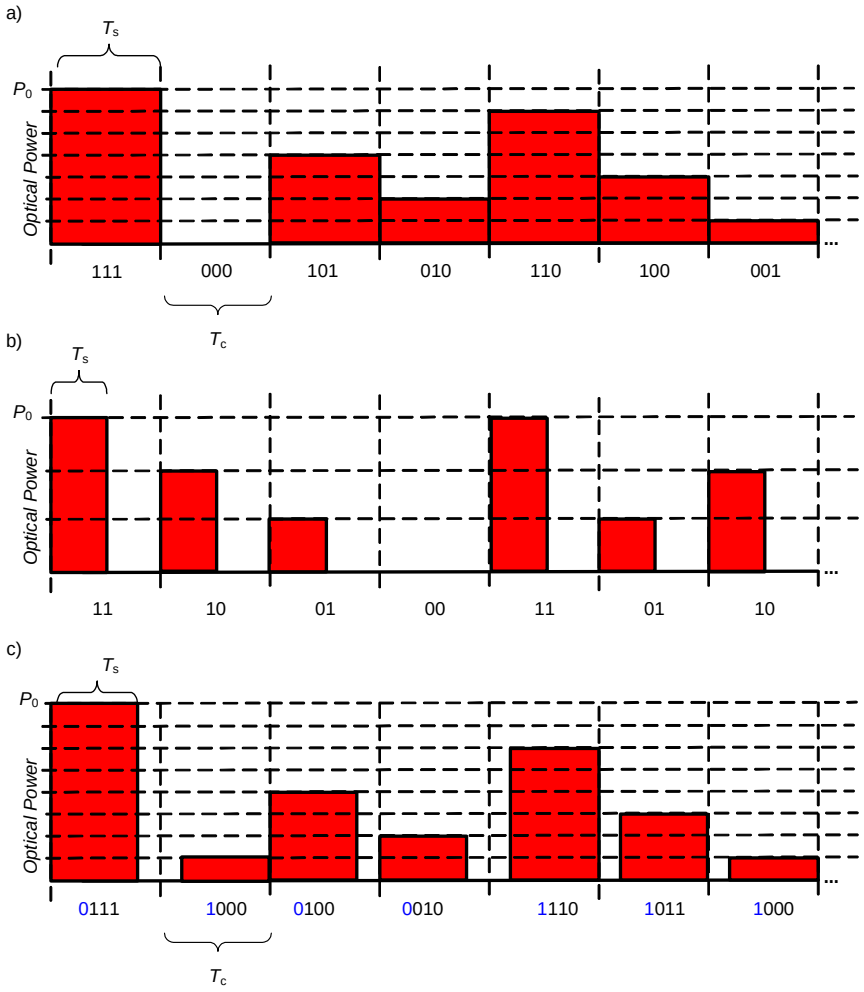
- Investigated two major approaches within OMEGA: Discrete multi-tone (OFDM, used in DSL) and multi-level PAM
- PAM supports higher data rates and simpler to implement [Randel, 2009]
- However: how to accommodate dimming?



Exploiting prevalent high SNRs: multi-level PAM, contd.

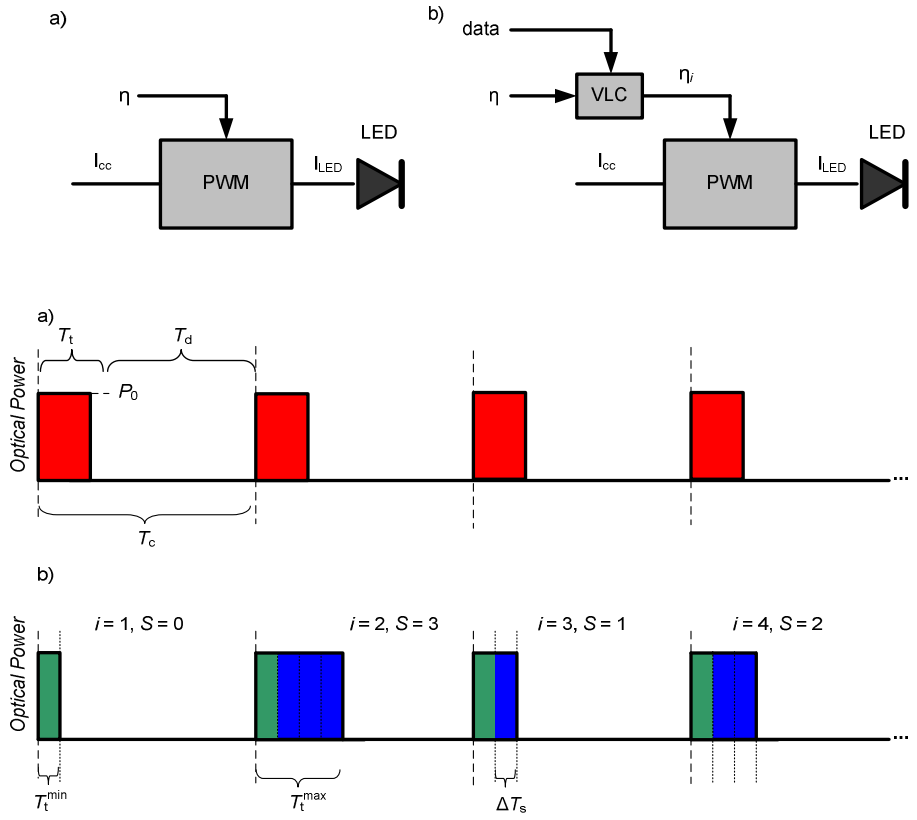
Accommodating dimming:

- Granularity of PAM symbols depends on length of “chip”
  - Low dimming → high granularity
  - High dimming → low granularity
- Seamless integration with VPM possible
- Flicker? Probably negligible. Simulations on request.



Exploiting prevalent high SNRs: symbol-length coding

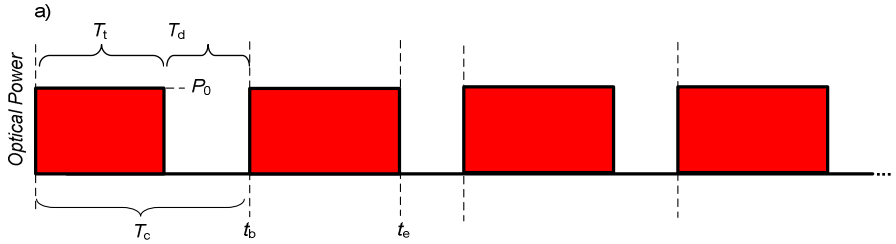
- Already in the base-line draft: alternating length of VPM symbols in order to achieve low-granularity dimming
- Proposal: map symbols onto alternation → symbol-length coding
- Can be combined with VPM
- Caution: no inherent flicker suppression. Simulation of expected flicker on request.
- Decrease granularity by flexibly choosing length of shortest chip and # of bits / symbol

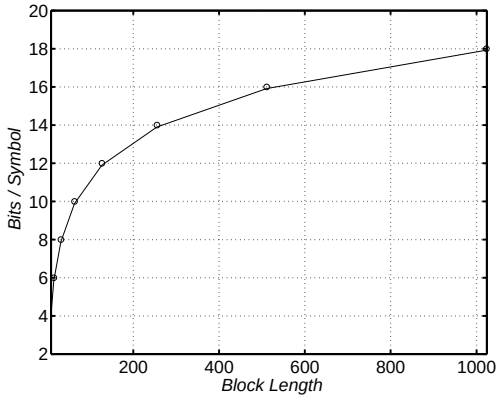


Exploiting prevalent high SNRs: symbol-length coding, contd.

Even higher data rates:

- Introduce dips into symbol
- When introducing several dips encode symbols onto relative position
- Example: time after beginning of symbol cluster





Bits per symbol as a function of the cluster length for two “dips”

Summary and Conclusions

- Many avenues of increasing data rate (in lighting scenarios)
- Op to TG whether, how, and when to integrate into standard
- Happy to provide more details on request in January

References

- Grubor et al., “Broadband Information Broadcasting Using LED-Based Interior Lighting,”J. Lightw. Technol., Vol. 26, 2008
- Randel et al., “Advanced Modulation Schemes for Short-Range Optical Communications,”J. Select. Top. Quant. Electr., submitted, 2009

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