**IEEE P802.15**

**Wireless Personal Area Networks**

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# Definitions

|  |  |
| --- | --- |
| OCC | Optical Camera Communication |
| OWC | Optical Wireless Communication |
| LiFi | High speed, bidirectional, networked and mobile wireless communications using light |
| MIMO | Multiple Input/Multiple Output |
|  |  |
|  |  |
|  |  |
|  |  |

# General Guidelines

This technical considerations document (TCD) describes the technical aspects that TG7r1 standard must fulfill, such as performance-related issues, reliability issues and availability issues. These types of requirements are often called quality of service (QoS) requirements; other requirements are usually maintenance-level requirements or external constraints, sometimes called compliance. Technical requirements are summarized as any other specifications; they have a name and a unique identifier. Technical requirements are documented in the same manner as any specifications, including a description, an example, a source or references to related technical requirements and a revision history. TG7r1 needs to effectively define and manage requirements to ensure they are meeting needs of the VLC (Visible Light Communication) users, while proving compliance.

Ideally, considerations should be:

• Correct technically and legally,

• Complete by expressing a whole idea or statement,

• Clear (i.e., unambiguous and not confusing),

• Consistent (not in conflict with other requirements),

• Verifiable, so that it can be determined that the system meets the requirements,

• Traceable (i.e., uniquely identified and track-able),

• Feasible, so that they can be accomplished within given cost and schedule limits,

• Modular, so that they can be changed without excessive impact to other requirements, and

• Design-independent, not to pose a specific solution on design.

Each consideration must first form a complete sentence, containing a subject and a predicate. These sentences must consistently use the verb “shall”, “will” or “must” to show the requirement's mandatory nature, and “should” or “may” to show that the requirement is optional. The whole requirement specifies a desired end goal or result and contains a success criterion or other measurable indication of the quality.

TCD needs to capture these levels of user requirements, maintaining intelligent traceability and change impact analysis between them.

Typical constraint considerations can specify:

• Performance,

• Interfaces,

• Security,

• Safety,

• Reliability,

• Availability, and

• Maintainability.

An efficient way of writing better requirements is to ensure they are clearly mapped to test cases. When specifying considerations or requirements, test cases must be considered to provide directions to help to verify requirements or considerations in the document. This can be provided by specifying a packet error rate and packet size for comparing contributions, for example. Making sure each requirement is clearly verifiable from the start, which not only helps to prepare later phases of the project, but it also puts the developer in the correct state of mind. Requirements and their associated tests must also indicate what the system should not do, and what happens at the limits (i.e., degraded mode). This rule also applies for compliance requirements: indicating how they shall be tested is a good way to write better requirements.

TCD needs to implement a reliable and repeatable change control process that helps turn this challenge into an opportunity.

By providing examples and counter-examples of good requirements and documents, IEEE can enhance the quality, consistency, and completeness of the requirements. These can originally be templates, industry standards and rules inside a repository, such as the IEEE server.

**Requirements for Typical Sentence Construction**

Defects to be avoided are:

* Vagueness,
* Weakness,
* Over specification,
* Subjectivity,
* Multiplicity,
* Unclear meaning, and
* Implicit meaning.

Some words listed below should be used with caution:

“adequate”, “applicable”, “appropriate”, “approximate”, “bad”, “best practice”, “between”, “clearly”, “compatible”, “completely”, “consider”, “could”, “down to”, “easy/easily”, “effective”, “efficient”, “equivalent”, “excellent”, “good”, “his/her”, “however”, “ideal”, “etc”, “in order to”, “include but shall not be limited to”, “least”, “like”, “low”, “maximise”, “may”, “most”, “minimum/minimal”, “must”, “nearly”, “necessary”, “needed”, “normal”, “or”, “possible/possibly”, “practicable”, “provide”, “quality”, “readily”, “relevant”, “safe/safely“, “same”, “should”, “significant”, “similar”, “so as”, “subject to”, “substantial”, “sufficient”, “suitable”, “support”, “target”, “typical”, “up to”, “user friendly”, “whether”, “will”, “with”, and “worse”.

**Difference between Considerations and Requirements (TCD vs. TRD)**

The TG7r1 group decided to use the term “considerations” instead of “requirements” in order to adopt a less rigid and formal process with the intention to be able to develop the standard quickly. This document serves to provide guidance for development of technical contributions for the IEEE 802.15.7r1 standard. The contents of the document are expected to be similar to a technical requirements document.

# Introduction

This document provides the technical contents of the project to develop PHY and MAC protocols for Optical Wireless Communications. This document will provide guidance on how to respond to a call for contributions.

This document serves two purposes:

1. It summarizes the applications presented in response to TG7r1 Call for Applications and questions and answers.
2. It describes and defines the fundamental requirements implied by the applications but not necessarily stated explicitly.

# Optical Wireless Communication

Optical Wireless Communication (OWC) is a wireless communication method using optical wavelength radio wave as the carrier wave.

OWC can be classified into:

**Optical Camera Communications** which enables short-range optical wireless communications using an image sensor as a receiver.

**LiFi** which is high-speed, bidirectional, networked and mobile wireless communications using light.

**LED-ID** which is wireless light ID system using various LEDs.

# Optical Camera Communication

## Applications/Use cases

The following OCC applications/use cases were presented in response to TG7r1 Call for Applications.

A1 Offline to Online Marketing/Public Information System [2, 3, 5, 6, 7]

A2 M2M/D2D/IoT/Internet of Light (IoL) [2, 3, 9, 10, 11]

A3 Indoor Positioning [2, 5, 10]

A4 Vehicular Communication [2, 7]

A5 Underwater Communication [8]

A6 Power Consumption Control [4]

A7 Vehicular Positioning [2]

A8 Seaside Communication [?]

The standard will consist of multiple PHY/MAC modes to meet the following variety of requirements.

## Transmitter

The standard should support the following devices as transmitters for each application.

|  |  |
| --- | --- |
| **Device** | **Applications/Use cases** |
| Ceiling light | A2, A3 |
| Flash light | A5 |
| Car light | A4, A7 |
| Indirect light | A1, A4 |
| Illuminated signage (with/without front panel) | A1 |
| Digital signage | A1 |
| Traffic light | A4, A7 |
| Lighthouse | A8 |

Ceiling light Flash light

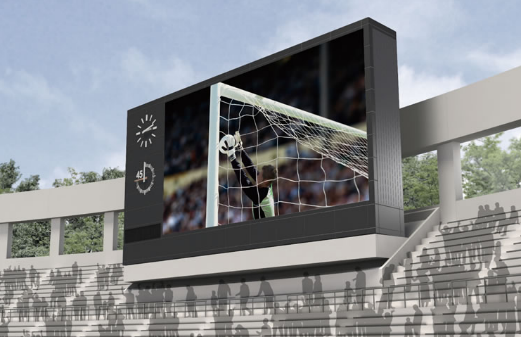
  

Car light Indirect light

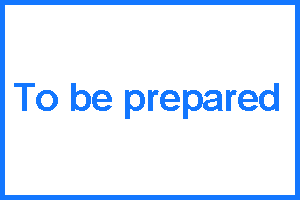
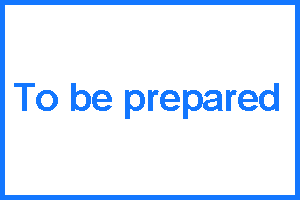
 

Illuminated signage Illuminated signage

with front panel without front panel

Digital signage

Traffic light Lighthouse

## Receiver

The standard will support optical camera, which has 2-dimentional array of photo sensors that measure intensity of visible light, IR and/or UV, as receiver. The standard will support image sensors of global/sequential shutter with multiple PHY/MAC modes.

## Carrier Frequency

Carrier frequency will be limited in visible light, IR and UV frequency band.

## Transfer mode

A PHY/MAC mode of the standard will support at least one of the following transfer mode:

**ID broadcast mode** which repetitively broadcast less than or equal to 128 bits of ID in a second with small overhead of MAC frame for application A1, A2, A3, A4 and A5.

**Unidirectional data transfer mode** which transmit longer data stream for application A2 and A4.

**Bidirectional data transfer mode** which enables efficient communication for application A2.

## Eye safety and Flicker

The modulated light will be safe for human eye in the aspects of frequency and intensity of light. And the modulated light will not stimulate sickness such as photosensitive epilepsy.

The standard will support at least one flicker free PHY mode, in which the modulation is imperceptible for human eye, for application A1, A3, A4, A7 and A8. The standard may allow flicker PHY mode for application A1, A2 and A5.

## Dimming Control

The standard will support dimming control for application A1, A3, A4 and A7.

## Communication Range

The standard should support communication range of

* + 0.1 meters to 10 meters for application A1
  + 0.5 meters to 100 meters for application A2
  + 1 kilo meter to 2 kilo meters for application A8

Communication range depends on the size and the brightness of a transmitter with some protocols, therefore communication range is measured in the condition of the size of 1 meter and the brightness of 300 Cd/m2 for performance comparison.

## Power Consumption Control

The standard should support power consumption control for application A6.

## Coexistence with Ambient Light

The standard will co-exist with ambient light that may be reflected on a surface of a transmitter.

## Coexistence with Other Lighting Systems

The standard will co-exist with other lighting systems. It will enable a receiver to receive a signal from a transmitter even if other lighting systems are captured in the same image frame, which are optically separable from the transmitter.

## Simultaneous Communication with Multiple Transmitters

The standard will support simultaneous communication with multiple coordinated/uncoordinated transmitters, which are separated on a captured image. Simultaneous communication with coordinated transmitters is called Multiple Input/Multiple Output (MIMO).

The standard may not support simultaneous communication with multiple signals reflected on the same surface because reflected light is not bright enough to employ complicated modulation scheme for mixed signal separation.

## Identification of Transmitter

The standard will support a scheme to identify transmitters when a receiver or a transmitter is moved. A receiver can trace a transmitter moving in captured images even if multiple transmitters is captured in a single image. A receiver can resume communication even if a transmitter is briefly out of sight.

## Error Detection

The standard will support an error detection scheme. Since a receiver cannot request re-transmission in ID broadcast mode and unidirectional data transfer mode, receiver will discard erroneous ID/data and wait re-transmission if error is detected. A receiver will request re-transmission in bidirectional data transfer mode for efficient communication.

## Waveform

The standard should employ square wave modulation (on-off keying) for simplification of modulation circuit. This will foster spread of the standard.

# LiFi

## Applications/Use cases

The following LiFi applications/use cases were presented in response to TG7r1 Call for Applications.

1. Indoor Office/Home Applications: (Conference Rooms, General Offices, Shopping Centres, Airports, Railways, Hospitals, Museums, Aircraft Cabins, Libraries etc.)
2. Data Center / Industrial Establishments (Personalized Manufacturing Cells, Factories, Hangers, etc.)
3. Vehicular Communications (Vehicle-to-vehicle, Vehicle-to-Infrastructure)
4. Wireless Backhaul (Small Cell Backhaul, Surveillance Backhaul, Lan Bridging)

These have been summarized in document number 15-15-0302-01-007a.

## Transmitter

The standard should support the following devices as transmitters for each application.

|  |  |
| --- | --- |
| **Device** | **Applications/Use cases** |
| Ceiling light | B1 – B3 |
| Indirect light | B1 |
| Car light | B3 |
| Directed lights | B2, B4 |

## Transfer mode

The standard will support **continuous data streaming** for all applications with bidirectional functionality. The standard must provide a PHY mode that allows the optimal use of the available optical bandwidth on a given luminaire for B1 – B4.

The standard must define a range of data rates from minimum supported connectivity or at least 10 Mbps to peak data rates of 10 Gbps.

The standard must define a range of latencies from maximum supported of at most 20 ms to minimum latency of 1 ms.

## Eye safety and Flicker

The modulated light will be safe for human eyes and will not stimulate photosensitive epilepsy. The standard should support flicker free PHY mode, in which the modulation is imperceptible for the human eye, for application B1 and B3.

## Dimming Control

The standard will support dimming control for application B1 – B3.

## Communication Range

The standard should support communication range between 0.1 meters to 5 meters for application B1 and B2, and communication range between 0.5 meters to 200 meters for applications B3 and B4

The communication range depends on multiple external factors (signal magnification, signal collimation, source power, etc.). These are implementation aspects and these numbers are provided as guidelines only. The committee will agree to use the same channel model to assess the performance capabilities of the proposed schemes.

## Multiple User Support

The standard must provide mechanisms to support multiple users receiving different data streams from the same light source (multiple access).

## Asynchronous Communication

The standard will support asynchronous communication between transmitters and receivers to allow higher data rates in one direction.

## Handover and Interference Coordination

The standard must provide mechanisms to support handover between light sources, allowing users to maintain a continuous network connection.

The standard must provide mechanisms that can be used to develop and deliver interference coordination techniques by higher layers.

## Localization

The standard must provide mechanism to support precise indoor positioning algorithms with less than 10 cm diameter precision.

## Coexistence with Ambient Light and Other Lighting Systems

The standard will co-exist with ambient light whose reflected brightness is less than xx % of brightness of a transmitter.

The standard will co-exist with other lighting systems. This will enable a receiver communicate with a supported transmitter even in the presence of other modulated lights.

## Simultaneous Communication with Multiple Transmitters

The standard will support interference coordination techniques to deal with simultaneous communication with multiple coordinated/uncoordinated transmitters.

It will support cooperative signal processing among multiple transmitters with negligible impact on latency.

## Error Detection

The standard will support an error detection scheme.

## Waveform

The standard will employ at least one PHY mode that uses variable current modulation.

# LED-ID

# References

1. The IEEE P802.15.7r1 Short-Range Optical Wireless Communications Task Group Project Authorization Request (PAR): https://mentor.ieee.org/802.15/dcn/15/15-15-0064-00-0007-p802-15-7-revision-par-approved-2014-12-10.pdf
2. Intel Response to 15.7r1 CFA: IEEE802.15-15-0146-00-007a
3. CASIO Response to 15.7r1 CFA: IEEE802.15-15-0173-01-007a
4. China Telecom CFA Response for Optical Camera Communications: IEEE802.15-15-0180-00-007a
5. Introduction of LED-ID and Smart Device Camera based Applications: IEEE802.15-15-0196-00-007a
6. Panasonic Response to 15.7r1 CFA: IEEE802.15-15-0197-00-007a
7. NTU Response to 15.7r1 CFA: IEEE802.15-15-0203-00-007a
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10. Kookmin University Response to 15.7r1 CFA: Application of OWC: IEEE802.15-15-0242-00-007a
11. Kookmin University Response to 15.7r1 CFA: Applications of OCC: IEEE802.15-15-0243-00-007a
12. Fraunhofer HHI Response to 15.7r1 CFA: IEEE802.15-15-0248-01-007a
13. pureLiFi\_CFA\_response: IEEE802.15-15-0192-00-007a