IEEE P802.11  
Wireless LANs

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| A CSD Proposal for Light Communications (LC) | | | | |
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Abstract

This is the IEEE 802.11 Light Communications (LC) SG proposed CSD.

# 1. IEEE 802 criteria for standards development (CSD)

The CSD documents an agreement between the WG and the Sponsor that provides a description of the project and the Sponsor's requirements more detailed than required in the PAR. The CSD consists of the project process requirements, 1.1, and the 5C requirements, 1.2.

## 1.1 Project process requirements

### 1.1.1 Managed objects

Describe the plan for developing a definition of managed objects. The plan shall specify one of the following:

1. The definitions will be part of this project. **YES**
2. The definitions will be part of a different project and provide the plan for that project or anticipated future project.
3. The definitions will not be developed and explain why such definitions are not needed.

### 1.1.2 Coexistence

A WG proposing a wireless project shall demonstrate coexistence through the preparation of a Coexistence Assurance (CA) document unless it is not applicable.

1. Will the WG create a CA document as part of the WG balloting process as described in Clause 13? **YES**
2. If not, explain why the CA document is not applicable.

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## 1.2 5C requirements

## 1.2.1 Broad Market Potential

Each proposed IEEE 802 LMSC standard shall have broad market potential. At a minimum, address the following areas:

a) Broad sets of applicability.

We live in an increasingly connected world. The demand for mobile wireless communications is increasing at nearly 50% per year according to the Cisco Visual Networking Index. Three numbers explicit the global ever-accelerating need for bandwidth and wireless: by 2021 more than half of 17 billion connected devices will be mobile, 65% of the IP traffic will be from mobile devices, 80% of the internet traffic will be video requiring high speed wireless.

There are multiple solutions that can provide an increase in the available spectrum and increase the spectrum reuse in a given area, as well as increased speed. WiGig solutions, defined in IEEE 802.11ad, .11mc, .11aj and 802.11ay are such examples. However, the continued deployment and growth of 802.11 technology relies on new technologies progressively being implemented to address a continued increase in capacity of wireless networks, and the availability of additional unlicensed spectrum, such as the visible and IR light frequency range. Additionally, non- RF based solutions may be preferred for multiple complementary use-cases, like environments where traditional RF solutions are not allowed due to safety and or securityEMI sensitive equipments, underwater communications, M2M or when security considerations prevents their use for example in banks and defense industry.

The light spectrum, for the most part, has been underutilised for free space communication because it was easier to provide mobility in large areas using RF. But with the ever increasing spatial reuse in smaller and smaller cells, a point will be reached where cells are so small that use of light as a medium for wireless communication becomes interesting. The visible light and near IR spectrum alone stretches from approximately 250 THz to 800 THz, which means that there is potentially more than 1000 times the bandwidth of the entire RF spectrum of approx. 300 GHz. Both the visible light spectrum and the infrared (IR) spectrum are unlicensed and could be used primarily in short-range wireless scenarios.

802.11 has had an IR standard in its early specification, where IR was a niche technology at that time due to the huge cost of powerful light sources and limited capabilities of electronics at that time. The key progress in the potential LC standard is that it would leverage the introduction and large scale deployment of high-power solid state light sources together with and large-area photodiodes and advanced electronics. Moreover, PHY and MAC technologies have evolved significantly from early days on and are now able to address existing use-cases for LC with enhanced performances as well as additional ones that emerged recently. Among those are volume markets for 802.11, such as industrial wireless, home and enterprise networks, backhauling scenarios as well as niches such as underwater communication and wireless access in medical environments. In addition, the pervasiveness of LEDs, technological maturity and the increasing demand for wireless capacity, low latency and high speed all play a significant role in the motivation for creating an LC standard within 802.11.

Since seminal work in 1979 [5], LC has been a subject of intense research & development with steady improvements in performance, cost, reliability and compactness [6-12]. While many applications have been imagined, it is intuitive that the exponential growth of LED lighting is shaping a huge market for LC in the next decade. LED lighting in 2016 accounted for <10% of the over 45 billion lighting sockets available. Yet, LED lighting accounted for more than 50% of the revenue for the lighting industry in 2016 and are fast replacing traditional light sources. It is anticipated that LED will replace over 70% of the current incandescent and fluorescent lighting by 2020. LC adds communications as new feature to LED lighting and thus offers significant market growth potential with over 550 million LED lights sold annually globally for a global $100bn general lighting market [1].

The LC technology uses unregulated spectrum of visible light that does not need licensing same as existing 802.11 technologies. It is exhibiting a low latency ideal for applications such as AR/VR and robotics and the high frequency modulation of LED and laser diodes gives access to the 1 to 10+ Gbps range [ ]. The intrinsically very small cells generated by LC access points integrated into the lighting infrastruture allow for a high density of point-to-multipoint communications capabilities at each light. respect norms and standards of the lighting industry so that they don’t represent don’t

LC are a powerful complement or alternative to RF, in environments where data exchange should be perfectly secure (banks, R\&D centers, defense, …), radio waves are not permitted or restricted (hospitals, pre-K schools, EMI sensitive industrial facilities such as natural gas compression stations) or connectivity should be guaranteed (conference rooms, hotels). The selection of use cases is driven by the facts that, on the one hand, the visible light frequency range is interference free and not regulated and, on the other hand, light communications happen inside the cone of the light. Obvious limitations of the technology, such as the fact that visible light has to be switched on (unlike IR) to facilitate data transmission, have to be acknowledged and constitute boundary conditions for the immense space of the use cases.

With increasing performances in terms of bandwidth, distance etc… many new use cases are unlocked: multi-person video calls, AR/VR, M2M communications, robotic telepresence, real time gaming ….

With people in industrialized nations spending more than 90% of their time indoors, lighting is poised to be a communications infrastructure of the future.

b) Multiple vendors and numerous users.

A significant variety of Light Communications (LC) vendors currently build various, non-standardized, products for many use-cases [4] spanning from kb/s IoT devices which work even with the diffused light up to few Gbit/s for mobile access points limited by realtime signal processing which is currently available. With the availability of new RF technologies, such as 802.11ax/ay, minor modifications of the existing PHY and MAC layers are sufficient to reach similarly high speed also for LC.

After demonstrating the benefit of LC in various use cases through pilots that have been recently and are currently conducted, it is clear that the demand for LC is growing. The LC market size is forecast to be worth $15 billion by 2022 according to Markets and Markets [2].

The availability of chipsets in the latest semiconductor technologies, which require high volumes, is seen as a key to reduce power consumption, form factor and costs for LC, same as for RF. Standardization is seen by the industry as a key requirement to address the mass market for LC. Vendors include chip makers to deliver PHY & MAC sub-systems, system integrators and lighting companies, telecom operators, ISPs, emerging IoT companies, large industrial manufacturers, aviation and transportation industries, etc. It is anticipated that the majority of those vendors, and others, will participate in the standards development process and drive the subsequent commercialization activities.

## 1.2.2 Compatibility

Each proposed IEEE 802 LMSC standard should be in conformance with IEEE Std 802, IEEE 802.1AC, and IEEE 802.1Q. If any variances in conformance emerge, they shall be thoroughly disclosed and reviewed with IEEE 802.1 WG prior to submitting a PAR to the Sponsor.

1. Will the proposed standard comply with IEEE Std 802, IEEE Std 802.1AC and IEEE Std 802.1Q? **YES**
2. If the answer to a) is no, supply the response from the IEEE 802.1 WG.

The review and response is not required if the proposed standard is an amendment or revision to an existing standard for which it has been previously determined that compliance with the above IEEE 802 standards is not possible. In this case, the CSD statement shall state that this is the case.

## 1.2.3 Distinct Identity

Each proposed IEEE 802 LMSC standard shall provide evidence of a distinct identity. Identify standards and standards projects with similar scopes and for each one describe why the proposed project is substantially different.

The project will have a narrow focus on the definition of the PHY and the lower part of the MAC layers to enable the use of the light spectrum for wireless communication primarily by using intensity modulation of the light source and direct detection using photodetectors.

The difference between LC and the other 802 standards in this field is the use of the 802.11 MAC and of large parts of its PHY as well as the reuse of associated services that are focused on wireless local area networks. This new approach will allow LC to leverage latest semiconductor technologies relative to 802.15.7m and 802.15.13 which can be regarded as intermediate steps focusing on deploying the early technology developments already in wireless specialty networks which have less challenging requirements on energy efficiency, form factor and cost.

Tight integration with 802.11, the coexistence and simplified hand-over with RF PHYs will reduce time-to-market for LC in its potential large-volume applications, e.g. together with lighting. Similar to the differences between the works on 60 GHz done in 802.15 and 802.11, existing work in 802.15 can be reused wherever possible while 802.11 technologies will more efficiently address new use cases having much larger volumes, besides the existing use-cases currently targetedby 802.15. The decision on the technical specifications of LC in 802.11 is the primary objective of the proposed task group on LC in 802.11.

## 1.2.4 Technical Feasibility

Each proposed IEEE 802 LMSC standard shall provide evidence that the project is technically feasible within the time frame of the project. At a minimum, address the following items to demonstrate technical feasibility:

a) Demonstrated system feasibility.

There are many publications demonstrating the hardware feasibility of LC. Greater detail on the technical feasibility of LC, including refreences for the demonstrated systems can be found here:

<https://mentor.ieee.org/802.11/dcn/17/11-17-0023-09-00lc-lc-tig-draft-report-outline.docx>

b) Proven similar technology via testing, modeling, simulation, etc.

IEEE 802.11 is a mature technology which has a variety of legacy devices and a proven track record, with several billions of deices shipping eachyear. The increased capabilities envisioned with LC for IEEE 802.11 are in line with the current progress in technology and not expected to impinge testability.

The TG for LC will develop similar tools for modeling and simulation to evaluate the appropriate performance metrics for LC.

**1.2.5 Economic Feasibility**

Each proposed IEEE 802 LMSC standard shall provide evidence of economic feasibility. Demonstrate, as far as can reasonably be estimated, the economic feasibility of the proposed project for its intended applications. Among the areas that may be addressed in the cost for performance analysis are the following:

a) Balanced costs (infrastructure versus attached stations).

The infrastructure costs are expected to be similar to the installation of traditional lighting or Ethernet based networks. In other words, very reasonable in terms of the delivered functionality.

1. b) Known cost factors.

LC technology is well characterized in terms of cost and is tended for devices, such as fixed assets and mobile devices, which are also well known and characterized in terms of cost. The addition of a LC chipset that is based substantially on existing 802.11 technology in LED lights creates a very good estimate for the infrastructure costs. Similarly, the presence of optical modules and communications modules in mobile devices allows for a very good estimate of the expected/potential impact on device costs.

c) Consideration of installation costs.

These are substantially similar to current installations for lighting and the market forces are driving demand independent of LC, in particular for Power over Ethernet solutions suitable for smart buildings.

d) Consideration of operational costs (e.g., energy consumption).

The added energy cost to support LC is minimal since the energy that is used for illumination may also be used to provide wireless communications. LEDs are being used for illumination and communications, removing constraints on the transmit power for the downlink.

Using LC for uplink can be more power consuming. However, as discussed in [3] (“how does uplink of LC-systems work”), when power consumption is an issue, the uplink could use infrared radiation or RF for uplink with similar level of power consumption as current 802.11 devices.

e) Other areas, as appropriate.

The light spectrum (100 nm – 10000 nm) is already considred licensed-exempt by some government regulators and falls outside of the remit of most other government regulators including outside of the regulatory authorities in Australia, Canada, China, India, Japan, Europe, South Korea and the USA.**References:**

1. Nikola Serafimovski, Christophe Jurczak, “IEEE 802.11-17/0803r1 Economic Considerations for Light Communications”
2. Global Market Insights, “Free Space Optics (FSO) and Visible Light Communication (VLC)”, available at http://www.marketsandmarkets.com/Market-Reports/visible-light-communication-market-946.html
3. Nikola Serafimovski et al. “IEEE 802.11-17/1048r0 Light Communications for 802.11”
4. Christophe Jurczak, “IEEE 802.11-17/1500r1 Light Communications Experience of a Lighting Systems Manufacturer”
5. F. Gfeller, U. Babst, “Wireless In-House Data Communication via Diffuse Infrared Radiation,” Proc. Of the IEEE, Vol. 67, No. 11, Nov. 1979.
6. J. M. Kahn, J. R. Barry, “[Wireless infrared communications](http://ieeexplore.ieee.org/abstract/document/554222/), “, Proc. of the IEEE, Vol. 85, No. 2, pp. 265-298
7. [T. Komine](http://ieeexplore.ieee.org/search/searchresult.jsp?searchWithin=%22Authors%22:.QT.T.%20Komine.QT.&newsearch=true); [M. Nakagawa](http://ieeexplore.ieee.org/search/searchresult.jsp?searchWithin=%22Authors%22:.QT.M.%20Nakagawa.QT.&newsearch=true), “Fundamental analysis for visible-light communication system using LED lights,” [IEEE Trans. Consumer Electronics](http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=30), Vol. 50, [No. 1](http://ieeexplore.ieee.org/xpl/tocresult.jsp?isnumber=28566), Feb. 2004, pp. 100 – 107
8. [M.Z. Afgani](http://ieeexplore.ieee.org/search/searchresult.jsp?searchWithin=%22Authors%22:.QT.M.Z.%20Afgani.QT.&newsearch=true) ; [H. Haas](http://ieeexplore.ieee.org/search/searchresult.jsp?searchWithin=%22Authors%22:.QT.H.%20Haas.QT.&newsearch=true) ; [H. Elgala](http://ieeexplore.ieee.org/search/searchresult.jsp?searchWithin=%22Authors%22:.QT.H.%20Elgala.QT.&newsearch=true) ; [D. Knipp](http://ieeexplore.ieee.org/search/searchresult.jsp?searchWithin=%22Authors%22:.QT.D.%20Knipp.QT.&newsearch=true), “ Visible light communication using OFDM,“ 2nd TRIDENTCOM 2006, March 1-3, 2006, Barcelona, Spain.
9. C. Kottke, J. Hilt, K. Habel, J. Vučić, and K. Langer, "1.25 Gbit/s Visible Light WDM Link based on DMT Modulation of a Single RGB LED Luminary," in Proc. ECOC 2012, paper We.3.B.4.
10. L. Grobe et al., "High-speed visible light communication systems," in IEEE Communications Magazine, vol. 51, no. 12, pp. 60-66, December 2013.
11. M. Ayyash et al., "Coexistence of WiFi and LiFi toward 5G: concepts, opportunities, and challenges," in IEEE Communications Magazine, vol. 54, no. 2, pp. 64-71, February 2016.
12. H. Chun et al., "LED Based Wavelength Division Multiplexed 10 Gb/s Visible Light Communications," in Journ. Lightwave Technology, vol. 34, no. 13, pp. 3047-3052, July1, 2016.