Charging Unplugged

Will Distributed Laser Charging for Mobile Wireless Power Transfer Work?

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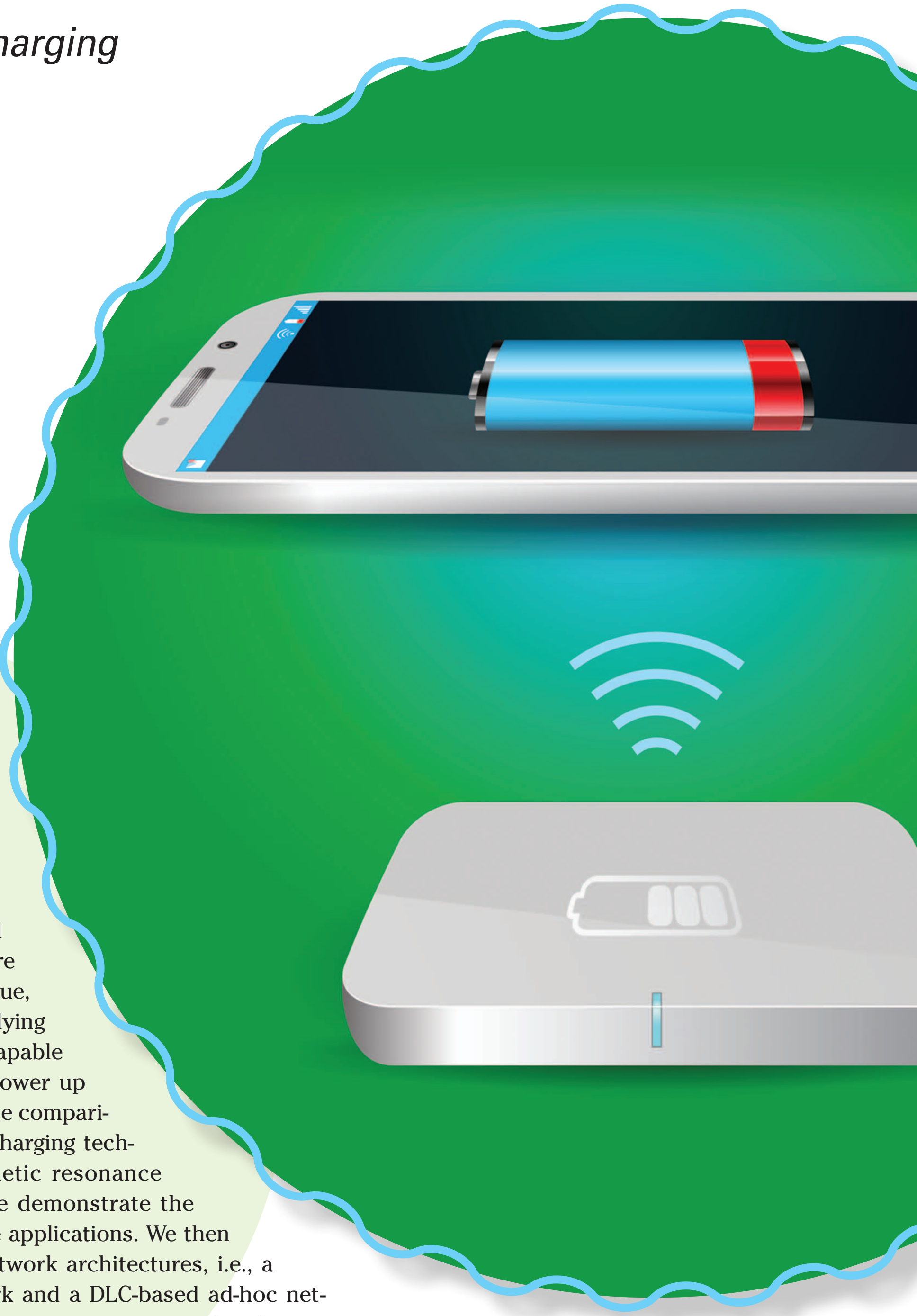

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Increasing the battery-recharge period of smartphones is becoming a challenge since their power consumption is increased as a result of enhanced functions that require sophisticated multimedia signal processing. An attractive solution is constituted by wireless charging, which is capable of replenishing the battery over the ether. Given this motivation, we present the fundamental physics and the related system structure of a promising wireless charging technique, i.e., distributed laser charging (DLC). Relying on DLC's unique features, we may be capable of transmitting approximately 2 W of power up to a distance of about 10 m. Following the comparison of the other three major wireless charging techniques, i.e., inductive coupling, magnetic resonance coupling, and microwave radiation, we demonstrate the benefits of DLC in the context of mobile applications. We then propose a pair of wireless charging network architectures, i.e., a DLC-aided, infrastructure-based network and a DLC-based ad-hoc network. These network architectures illustrate the potential of DLC in realizing the fully charged utopia for any device, anywhere, and anytime.

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Background

The increasing power consumption of smartphones is tangibly demonstrated by the fact that the second-generation phones' 20 million floating-point operations per second (MFlops) complexity was increased to above 100 MFlops for their third-generation counterpart, which was further increased by the fourth-generation phones. Sub-1 V nanotechnology is capable of mitigating the power consumption; however, it is vulnerable to electromagnetic interference (EMI). On the other hand, charging mobile devices like smartphones, tablets, laptops, and wearables imposes the daily nuisance of having to carry a power cord and finding a power source. Therefore, the paradigm of charging any device, anywhere, anytime has drawn substantial research attention.

More than a century ago, Nikola Tesla entered science history for his ground-breaking invention of alternating-current electricity and for his Wardenclyffe Tower project that aimed at transferring electrical energy without cords through the ionosphere [1]. His pioneering adventures have motivated scientists and engineers to conceive more practical wireless power transmission techniques. Wireless power transmission, or wireless charging, is the technology of transmitting electrical power from a power source to electronic devices or batteries without using wires. The benefits of wireless charging have been summarized in [2] in terms of user convenience, product durability, usage flexibility, and on-demand availability. Currently, the three major techniques of wireless charging are magnetic inductive coupling, magnetic resonance coupling, and microwave radiation, which are surveyed in [2] in terms of their advantages, disadvantages, effective charging distances, and applications. The wireless charging standards of Qi and the Alliance for Wireless Power are also reviewed in [2].

Following the transfiguration of desk phones to cell phones, of desktop computers to laptops and tablets, and of fixed electronic devices to wearable devices, mobility has become a key feature of most electronic devices; however, the aforementioned wireless charging techniques still face critical challenges [2]. For example, inductive coupling is not suitable for certain applications due to the associated short charging distances, ranging from a few millimeters to a few centimeters. The family of magnetic resonance coupling techniques also has its own impediments since it is a challenge to reduce the coil size to be implemented in portable devices and it is also hard to tune the resonator, where the operational distance ranges from a few centimeters to a few meters. By contrast, microwave radiation is capable of transmitting power up to several kilometers. However, it is difficult to collimate to the target device and unsafe when the radio-frequency (RF) density exposure is high. Although beamforming and energy harvesting based on microwave radiation have been proposed, their reliability and availability are limited by administrative regulations, such as those issued by the U.S. Federal Communications Commission, due to the associated safety and health considerations. Thus, RF power transfer remains in the milli/micro-W range, which is not practical for charging typical smartphones, laptops, and more [3], [4]. Apart from these three techniques, DLC is one new idea for wireless power transmission that is especially suitable for safe mobile applications. The practical DLC systems, providing 2-W power up to a 10-m distance, are currently under development by Wi-Charge, etc., for typical mobile devices [5].

DLC

Laser Fundamentals

The word *laser* refers to light amplification by stimulated emission of radiation [6], which is widely used in devices that we operate in our daily lives, such as laser pointers, laser printers, barcode scanners, and disk burners and players. Figure 1 illustrates a pair of parallel mirrors, M1 and M2, in conjunction with a gain medium made of gallium arsenide (GaAs), for example, which is used for emitting the photons (small, energy-carrying light particles) excited (or pumped) by an external power source [5]. The gain medium puts the atoms or molecules into an upper excited state by elevating them from a lower state. These excited atoms or molecules will transit from the upper state to the lower state spontaneously, which leads to photon emissions.

A photon is indicated by a single arrow in Figure 1. A photon originating from mirror M1 enters the gain medium, and, in response, a pair of photons is emitted, as illustrated by the thick green arrows. Naturally, this is a simplistic way of describing the amplification process by the gain medium, invoked for conceptual clarity. This pair of photons travels toward the mirror M2, where they are reflected back toward mirror M1, as represented by the pair of red u-shaped arrows next to M2. Then, these two photons pass through the gain medium again and stimulate four photons that are emitted toward M1, as indicated by the four red arrows pointing to M1. Thus,

CURRENTLY, THE THREE MAJOR TECHNIQUES OF WIRELESS CHARGING ARE MAGNETIC INDUCTIVE COUPLING, MAGNETIC RESONANCE COUPLING, AND MICROWAVE RADIATION.

each photon passing through the gain medium increases the power of the recirculating light between M1 and M2. This process of positive feedback is termed *resonation*, where the resonator consists of a pair of mirrors and a gain medium.

As shown in Figure 1, the line perpendicular to the M1 and M2 mirror surfaces is referred to as the *main axis*. Only photons that travel exactly parallel to the main axis are amplified, while those that are even slightly skewed will be scattered and exit from the resonator, which is shown by the black arrows in Figure 1. Therefore, the resonating power is concentrated along the main axis only. In general, the mirror M1 is perfectly reflective, with 100% reflectivity, while M2 is semitransparent and associated with approximately 95% reflectivity. This allows a small fraction of the light power to leave the resonator from M2 and creates a very sharp high-power light beam. This beam is known as the *laser beam*, which is depicted by the yellow arrows in Figure 1.

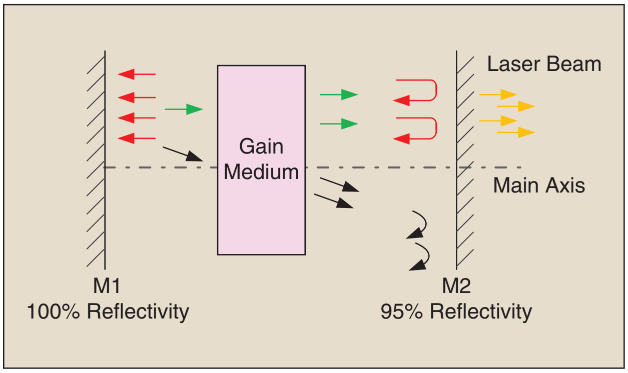

FIGURE 1 The laser fundamentals. (Based on [5].)

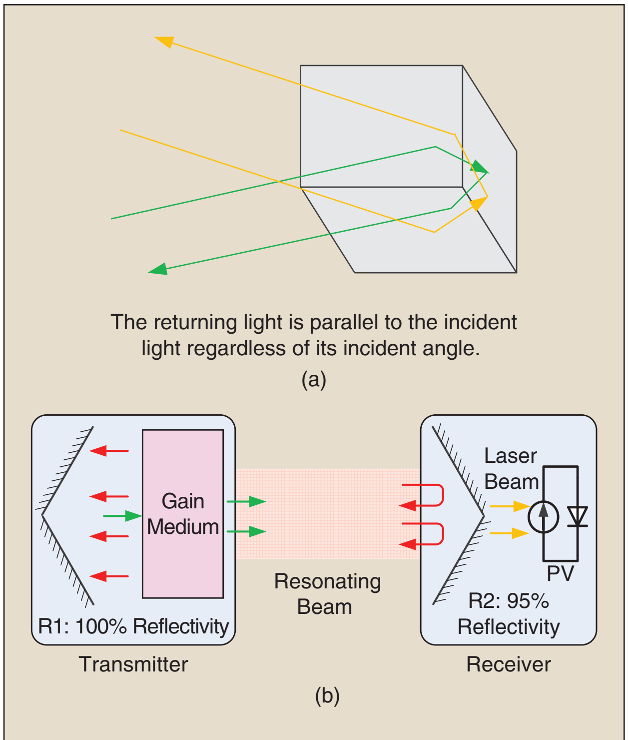

FIGURE 2 A DLC. (Based on [5].)

Increasing the pump power exciting the GaAs gain medium leads to an increased power loss since the photons are increasingly scattering off the resonator. When the net gain (gain minus loss) attained reduces to unity, the gain medium is said to be saturated. This equilibrium determines the operating point of the laser [6]. In summary, a laser is generated by a resonator, and it is characterized by a narrow, high-power collimated beam, which can be sent over long distances. A laser's key features include

1) *monochromaticity*: a laser beam is concentrated in a narrow range of wavelengths
2) *coherence*: all the emitted photons bear a constant phase relationship with each other
3) *directionality*: a laser beam typically exhibits low divergence [6].

Distributed Resonating Laser

A retroreflector is a device or surface that reflects light back to its source's direction, regardless of its angle of incidence [7]. For example, as seen in Figure 2(a), the structure of three mirrors arranged perpendicularly to each other in a corner forms such a retroreflector. For the regular flat-panel mirror seen in Figure 1, the reflected light is parallel to its incident [7] light if, and only if, the angle of incidence is vertical to the mirror. However, for a retroreflector mirror, the reflected light is parallel to its incident counterpart regardless of its angle of incidence. Retroreflectors are commonly used in safety clothing, road signs, bicycle reflectors, and so on.

Figure 2(b) portrays a laser resonator consisting of a gain medium and the pair of retroreflector mirrors, R1 and R2 [5]. In this resonator, the photons that do not travel along the line connecting R1 and R2 fly away without being amplified, as detailed in the section "Laser Fundamentals." Only the photons that travel along the line connecting R1 and R2 can reach a retroreflector and are, hence, reflected back to the other. These photons are amplified while passing through the gain medium. This process generates a resonating beam, regardless of the specific angles of incidence, as long as R1 and R2 are in the line-of-sight (LOS) of each other. This resonator differs from the regular laser resonator of the section "Laser Fundamentals" as follows.

- R1 and R2 spontaneously form a resonator, regardless of the incident angle, as long as they are in the LOS of each other.
- A foreign object between R1 and R2 stops amplification immediately because the photons cannot resonate through an obstacle.

Similarly, as detailed in the "Laser Fundamentals" section, a laser beam can be generated if R2 is semitransparent. A photovoltaic (PV) cell can be installed behind R2 to convert laser light to electrical energy in a way similar to a solar panel. We refer to the combination of R1 and the gain medium as a *transmitter* and to the combination of R2 and the PV cell as a *receiver*. Whenever the receiver is within the LOS of the transmitter, a resonating beam may be formed, where power is delivered by the resonating beam from the transmitter to the receiver.

Typical laser systems integrate resonator components in a single device, and the laser beam exits the device, which is referred to as an *integrated resonating laser*. However, the laser system considered here distributes the resonator components to the transmitter and the receiver, respectively, where they are spatially separated. This laser may be termed a *distributed resonating laser*. We refer to the wireless charging technique based on the distributed resonating laser as *DLC*.

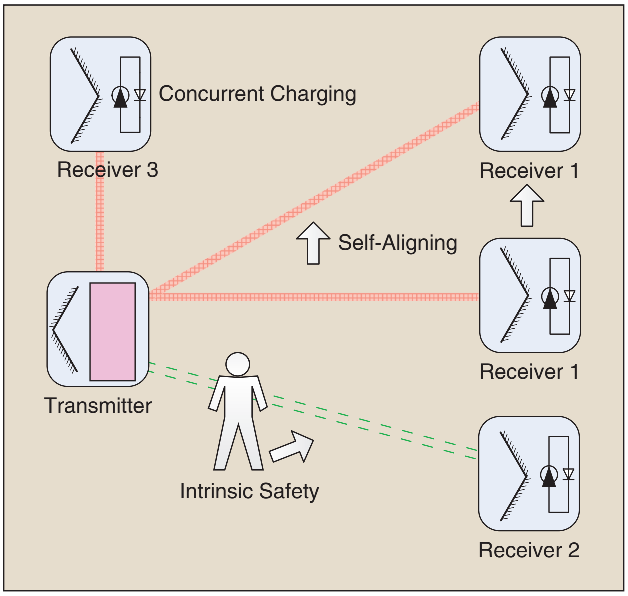

FIGURE 3 The DLC features.

DLC Features

Self-Aligning

Mobile charging can be realized as long as the transmitter and the receiver are in the LOS view of each other. In this situation, the distributed resonator (consisting of the two retroreflectors plus the gain medium) can generate a resonating beam without the assistance of specific aiming or tracking. No user action to initiate the charging process in DLC leads to a Wi-Fi-like experience, which is in contrast to a wired charger or a typical wireless charging pad. We refer to this feature as *self-aligning*, which is portrayed in Figure 3, where the resonating beam can be self-established when Receiver 1 changes its position.

Intrinsically Safe

The DLC power level may reach tens of watts, which is over most consumer electronics' power need [5]. On first consideration, this might raise safety concerns. However, DLC is different from integrated resonating lasers owing to its spatially distributed resonator structure. Upon encountering an obstruction along the resonating beam path, the resonation ceases at the speed of light since the photons are blocked by the obstacle. Thus, the laser action is curtailed immediately without any software or decision-making circuitry involvement. The distributed resonator only delivers energy along an unobstructed line from the transmitter to the receiver. We denote this feature as *intrinsically safe*, as shown in Figure 3. In this example, a person is entering the resonating beam path spanning to Receiver 2, which instantly blocks the wireless power transmission to Receiver 2 by blocking the LOS path between the transmitter and Receiver 2.

Concurrently Charging

As discussed in the "Distributed Resonating Laser" section, when a receiver is placed in the LOS path of a transmitter, a DLC resonating beam can be generated between them. Thus, a single transmitter is capable of creating several resonating beams that point to multiple receivers, which facilitates concurrent wireless charging from a single transmitter to multiple receivers [5]. We refer to this feature as *concurrently charging* multiple receivers, as shown in Figure 3, where Receiver 1 and Receiver 3 are being charged simultaneously.

Hot-Spot Charging

The effective range of a distributed resonating laser is typically shorter than that of an integrated resonator laser, but, nonetheless, distances of up to 100 m may be achievable [5]. This range is substantially higher than that of typical inductive coupling and magnetic resonance coupling, given the same transmitter and receiver size and power level. Relying on its self-aligning feature, DLC is capable of providing a certain wireless charging coverage area, where the effective resonating beam can be generated between the transmitter and the receiver. For example, an indoor DLC transmitter placed on the ceiling is capable of covering a hot-spot area of about 50 m^2. Therefore, DLC may be deemed suitable for charging consumer electronics and providing a Wi-Fi-like hot-spot charging experience. Indeed, a prototype DLC system designed by Wi-Charge to deliver up to 2 W of

DLC MAY BE CAPABLE OF SAFELY PROVIDING 2-W POWER, REACHING UP TO A DISTANCE OF 10 M FOR MOBILE DEVICES.

power [5] is capable of simultaneously charging several laptops and smartphones.

Compact Size

The DLC receiver can be designed to be compact, i.e., as small as a smartphone camera [5], where the resonating beam's diameter is about a millimeter or so.

EMI-Free

DLC does not leak any significant amount of power outside the resonating beam. In contrast to other wireless charging techniques, DLC imposes no RF radiation. Therefore, it inflicts no EMI upon the surrounding electronic devices.

Wavelength-Agnostic

DLC may rely on the employment of both visible as well as infrared and ultraviolet lasers. Both the infrared and ultraviolet resonating beams are invisible, which may hence be deemed eminently suitable for consumer electronics since no visible light interference will be imposed. By contrast, other applications, such as the charging of audio entertainment devices, may prefer visible resonating beams, which create a conspicuous audio, mobile phone, tablet, laptop, and headphone charging hot spot, just to name a few. DLC's visibility-agnostic characteristic enables system design flexibility in different applications.

Simultaneous Wireless Information and Power Transfer-Ready

Simultaneous wireless information and power transfer (SWIPT) is possible, provided that the communication and the networking modules are integrated in the DLC transmitter and receiver. Visible- or invisible-light-based communication techniques can be codesigned with the aid of DLC for realizing SWIPT [3], [8], [9]. Furthermore, both control signaling and wireless power transmission can be integrated in a single resonating beam without any reliance on classic radio communications such as Wi-Fi, Bluetooth, and so on.

Location-Based Services-Ready

Location-based service (LBS) functions can be integrated into a DLC system. A DLC-based positioning system can be realized by invoking a charge-coupled-device-assisted image sensor in the transmitter. Therefore, the resonating beam can be mapped as a spot on a bird-eye camera-like image sensor, which estimates the angle of the receiver relative to the transmitter on a two-dimensional surface. At the same time, the distance between the transmitter and the receiver can be readily obtained by measuring the round-trip time of a laser pulse. Therefore, the three-dimensional position of the receiver relative to the transmitter can be conveniently derived by combining the angle and distance estimates. Since the typical measurement accuracy of the laser angle and timing is usually better than that of classic RF-based positioning techniques [10], the DLC-based positioning system can be used for accurate LBS.

LOS-Dependent

DLC also has its limitations. Having an LOS path between the transmitter and the receiver is necessary for generating the resonating beam.

In Summary

DLC is self-aligning, intrinsically safe, and capable of supporting concurrent multiple-receiver hot-spot charging. It has a compact size, and it supports EMI-free operation; however, it is inherently LOS-dependent. Furthermore, DLC can be wavelength-agnostic and SWIPT-ready as well as LBS-ready.

Comparison of Wireless Charging Techniques

To compare DLC to different wireless charging techniques, we refer to [2, Table I] and add the DLC features discussed in the “DLC Features” section to form Table 1. Based on our comparison of their advantages, disadvantages, and effective charging distances as well as potential applications, the DLC philosophy may be deemed suitable for LOS-based mobile applications. For example, DLC may be capable of safely providing 2-W power, reaching up to a distance of 10 m for mobile devices, such as smartphones, laptops, wearable devices, home and office electronics, robots, and so on [5].

DLC has the same advantages as other laser power transmissions, which include the following.

- Large distance. The associated collimated monochromatic wavefront propagation facilitates having a narrow-beam cross-section area for transmission over large distances.
- Compact size. Solid-state lasers can fit into compact consumer products.
- EMI-free. No RF interference is imposed on existing radio communications, such as Wi-Fi and cell phones.
- Access control. Only receivers hit by the laser can receive power.

On the other hand, the concerns of laser power transmission as well as DLC include the following.

- Conversion efficiency. Conversion from electronic energy to light is inefficient. Typical PV cells can only achieve 40–50% efficiency with monochromatic light, although this is higher than that of solar panels.

TABLE 1 A comparison of different wireless charging techniques.

Wireless Charging Technique	Advantage	Disadvantage	Effective Charging Distance	Applications
Inductive coupling	Safe for humans, simple implementation	Short charging distance, heating effect; not suitable for mobile applications, needs tight alignment of the charger and charged devices	From a few millimeters to a few centimeters	Mobile electronics (e.g., smartphones and tablets), toothbrushes, RFID tags, contactless smartcards
Magnetic resonance coupling	Loose alignment between chargers and charged devices, charging multiple devices simultaneously at different power; high charging efficiency, NLOS charging	Not suitable for mobile applications; limited charging distance; complex implementation	From a few centimeters to a few meters	Mobile electronics, home appliances (e.g., TV and desktop), electric vehicle charging
Microwave radiation	Long effective charging distance; suitable for mobile applications	Not safe when the RF density exposure is high; low charging efficiency	Typically from tens of meters, up to several kilometers	RFID cards, wireless sensors, implanted body devices, LEDs
DLC	Self-aligning, safe, multiple-Rx charging, high power, compact size, EMI-free, visibility-agnostic, SWIPT-ready, LBS-ready; suitable for mobile applications	LOS required; low charging efficiency	Up to 10 m	Mobile devices (e.g., cell phone, laptop, tablet, wearable devices, drone), consumer electronics (e.g., projector, speaker, toothbrush), sensors, LEDs

NLOS: non–line-of-sight, Rx: receiver, RFID: RF identification, LEDs: light-emitting diodes.

- Laser hazard. A laser can blind or even kill humans by localized spot heating. However, DLC is intrinsically safe since any obstruction blocking the resonating beam will curtail power transmission at the speed of light.
- Propagation attenuation. Laser energy attenuation in clean air is very low although it becomes significant due to atmospheric absorption and scattering by clouds, fog, rain, etc.

DLC-Powered Networks

DLC Infrastructural Network

Deploying DLC transmitters to charge DLC-receiver-aided devices will lead to improved convenience in people's daily life. Wi-Charge, Inc., demonstrated the feasibility of the DLC transmitter and receiver [5]. As seen in Figure 4, a DLC transmitter can be combined with a light-emitting diode (LED) array to become a DLC-equipped lightbulb. Therefore, this DLC-equipped lightbulb can be conveniently installed to provide both an illumination and a power-charging capability. The DLC transmitter's size would not substantially increase the regular LED-array size. The DLC receiver size can be at the centimeter level and may be readily embedded in mobile devices, such as smartphones, laptops, tablets, and so on. The DLC-equipped LED array should have a power-charging coverage similar to its illuminating coverage, providing wireless power charging reminiscent of Wi-Fi communications. Due to its LOS limitation, ceiling installation of the DLC transmitter is preferred.

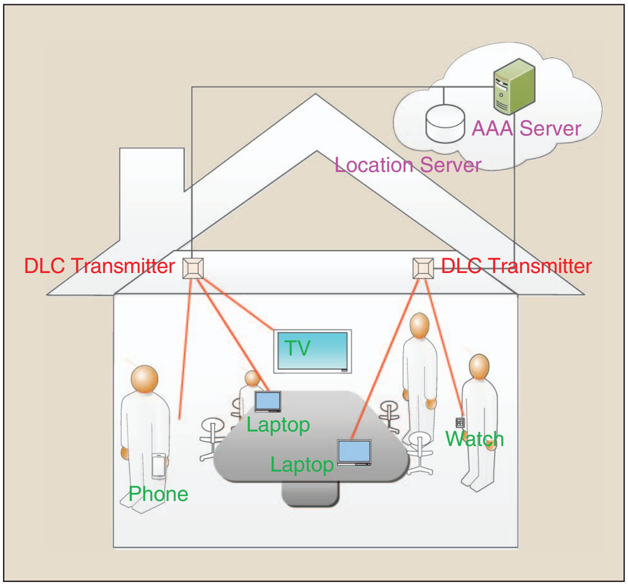

FIGURE 4 A DLC infrastructural network.

Ubiquitous DLC services can be provided, similar to cellular communications or public illumination.

Apart from wireless charging, as discussed in the "DLC Features" section, the DLC networks are also capable of supporting other applications, such as LBS, security surveillance, and so on. For example, security camera installations usually involve wiring difficulties due to the lack of power supply availability. By contrast, a DLC-receiver equipped camera facilitates convenient installation and flexibility. Similar wiring problems may occur for other electronic devices, such as projectors, active speakers, television sets, etc.

Ubiquitous DLC services can be provided, similar to cellular communications or public illumination. However, this requires considerable financial investments. The DLC infrastructure may be commercialized for wireless power-charging services at a reasonable cost. The pioneering research on the architecture and protocol of wireless charger networks was presented by Lu et al. [2]. Referring to the proposal in [2], a promising business proposition may be created to operate the DLC infrastructure at high-user-density locations, such as airports, train stations, restaurants, hotels, and other public venues. DLC supports concurrent charging for providing wireless power to multiple devices. However, the implementation of network management systems, including resource allocation, authentication, authorization, and accounting (AAA), in DLC networks requires further research. For example, a mobile device equipped with a DLC receiver may be authenticated—via Wi-Fi or long-term evolution (LTE)—with the aid of the authentication server of the DLC network. Once the service request has been authorized, the AAA server may inform the DLC transmitter to initiate the DLC service for the mobile device. The user experience of wireless charging may be deemed reminiscent of Wi-Fi/LTE in data communications.

Ad-Hoc DLC Networks

As seen in Figure 5, a compact DLC receiver can be mounted on a battery-powered off-the-shelf drone for charging the drone's battery. A DLC transmitter (termed a *power base station*) on the ground can provide a laser-based power supply for the drone. Since the DLC is capable of self-alignment and a LOS propagation is usually available, the drone can be charged as long as it is flying within the DLC's coverage range. Thus, this DLC-equipped drone can operate for a long time without landing until the maintenance is needed. As discussed in the "DLC Features" section, a DLC system providing a 2-W, 10-m wireless power supply is capable of supporting such an application.

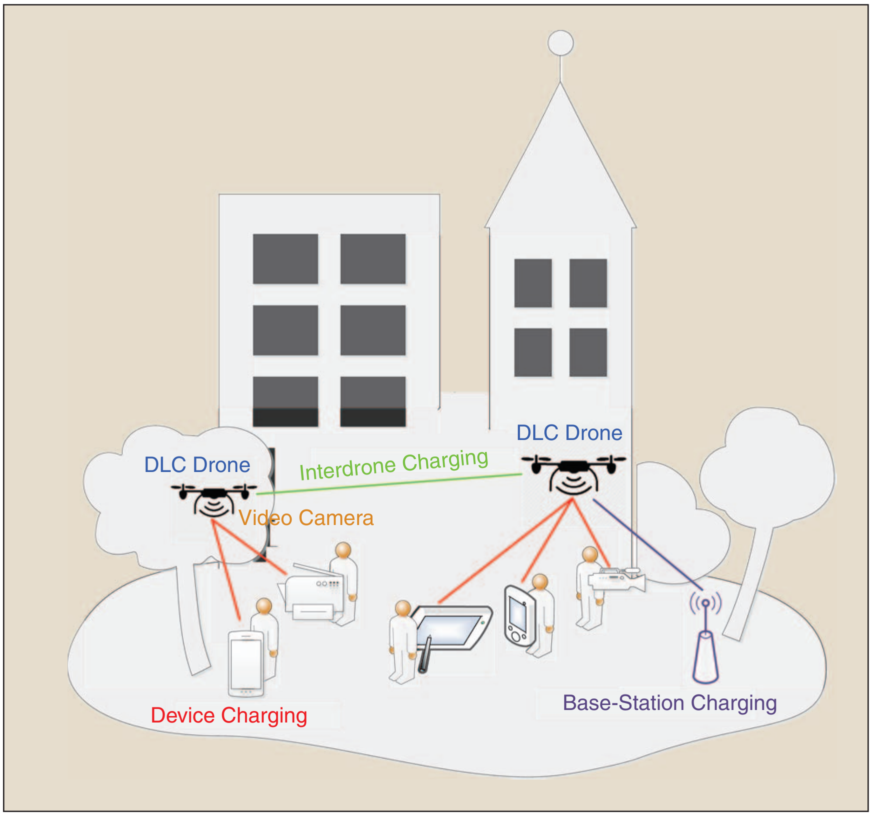

FIGURE 5 A DLC ad-hoc network.

A DLC transmitter can also be combined with a DLC receiver in a single drone. In this case, the drone becomes capable of playing the role of a DLC relay. This DLC relay drone, hence, becomes capable of charging other DLC receivers within its coverage range. Therefore, an ad-hoc wirelessly powered network can be established by the DLC-equipped drones. Moreover, a dynamic network organization can be adopted for attractive future applications by using intelligent cooperative algorithms. For example, multiple DLC transmitters can be used for charging a single device as well. Such a network may be readily established at a public event serving a large user population at festive ceremonies and concerts, in a sports stadium, and so on, where occasionally on-demand wireless power charging is necessitated. This may be achieved without building a permanent infrastructure. Beyond power transmission, this network can also be used for data communication, security surveillance, location tracking, and more. Nonetheless, the power-charging efficiency and the battery life of such a DLC-aided ad-hoc network has to be further studied, which will be discussed next.

Open Issues and Future Research

There are several open issues and research directions for the DLC techniques considered.

- The maximum achievable power-conversion efficiency is one of the major concerns for DLC systems. Again, PV cells are capable of achieving a 40–50% efficiency with the aid of monochromatic light, such as laser light [11]. The attainable efficiency is higher than that of normal solar panels, whose efficiency typically ranges from 10–20% [12]. By contrast, the lithium-ion battery charging and discharging efficiency can be as high as 99% [13]. The electrical-to-laser conversion efficiency varies from 25–76% [14]. As exemplified by the interdrone DLC power transmission scenario of the "Ad-Hoc DLC Networks" section, the associated power conversion stages are illustrated in Figure 6(a), which include
  - the transmitter battery discharging having a 99% efficiency
  - the transmitter's electrical-to-laser conversion efficiency of 25–76%
  - the receiver's laser-to-electrical conversion efficiency of 40–50%
  - the receiver's battery charging with a 99% efficiency.
- The overall conversion efficiency between the transmitter's and receiver's batteries is given by the product of these four factors, assuming that the resonating beam's propagation loss is negligible. Figure 6(b) shows the overall power conversion efficiency from the transmitter's battery to the receiver's battery versus the electrical-to-laser power conversion efficiency, given the laser-to-electrical PV efficiency of 40% and 50%, respectively. The overall conversion efficiency varies from 10–37%, which indicates that there is considerable space for improvement. Moreover, the thermal effects of DLC systems have not been widely investigated in the open literature. Furthermore, the choice of wavelengths achieving the best power transmission efficiency and the selection of appropriate performance metrics should also be studied.
- In contrast to the integrated resonating laser, DLC is intrinsically safe, where laser power is transferred from the transmitter to the receiver only. DLC is physically incapable of delivering any power to foreign objects, including human tissues [5]. However, this cautious optimism should stimulate further safety-related studies of DLC since this subject has not been investigated in many important specific situations, as exemplified by absorption and scattering by glass, smoke, steam, and so on. Furthermore, the safety concerns of the photons scattering off the R1–R2 LOS direction in Figure 2(b) should also be further investigated. Hence, safety investigations constitute the pivotal research direction of this promising DLC technique.
- The laser propagation loss in outdoor applications is significantly affected by the weather, especially by rain, fog, snow, and so on, which has been investigated in [15]. However, there is a paucity of literature on the DLC's propagation-induced resonating beam power loss. These path-loss aspects impose significant constraints on the effective DLC transmission distance, which requires further research.
- Requiring LOS in DLC power transmission limits the convenience of charging mobile devices. Reducing the blind angle to increase the availability of an LOS path may lead to innovative DLC system designs and architectures. For example, the shape of the retroflecting DLC receiver may be designed to have a spherical surface to maximize the useful angle of reception. Furthermore, innovative cooperative techniques may be conceived for avoiding obstacles in the LOS path. Therefore, creative ideas are needed for improving the

THE DLC INFRASTRUCTURE MAY BE COMMERCIALIZED FOR WIRELESS POWER-CHARGING SERVICES AT A REASONABLE COST.

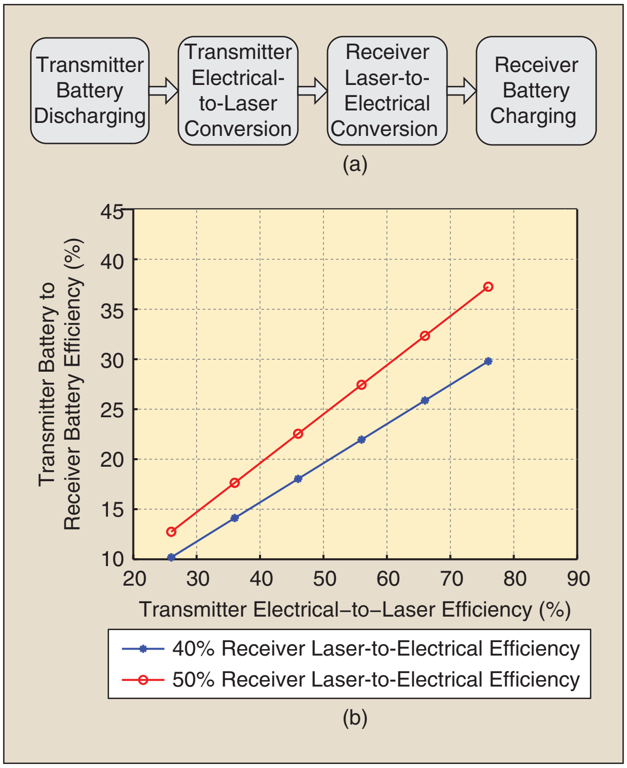

FIGURE 6. The DLC conversion efficiency.

CAREFULLY ADAPTING THE WELL-DEVELOPED SCIENCE AND TECHNOLOGY OF WIRELESS COMMUNICATIONS FOR DLC RESEARCH AND DEVELOPMENT CONSTITUTES A COMPELLING RESEARCH PROPOSITION.

DLC quality-of-service. A possible solution is to build a wireless charging relay, which assists the DLC receiver with the aid of other non–LOS (NLOS) wireless charging transmitters, such as a magnetic resonating transmitter. Although this may lead to other concerns, such a hybrid charger may be capable of supporting NLOS mobile wireless transmission.

- The DLC network architecture was briefly discussed in the "DLC-Powered Networks" section, but the related protocols conceived for power charging, data communications, LBSs, etc., must be further developed.
- The DLC and wireless communication schemes exhibit some similarities. For example, they aim for efficiently transmitting energy and information, respectively. Additionally, their transmitter/receiver structures are similar. Hence, carefully adapting the well-developed science and technology of wireless communications for DLC research and development constitutes a compelling research proposition.
- Another concern is the capability of tracking a mobile receiver in DLC systems. Intuitively, achieving this ambitious goal is more challenging than the employment of other wireless power transfer techniques, primarily due to the significantly shorter wavelength of the laser beam. However, given the paucity of literature on DLC receiver tracking, this currently remains an open challenge, thus motivating future research.

In a nutshell, both academic research and practical DLC developments are in their infancy; hence, many technical aspects have remained hitherto unanswered.

Conclusions

Wireless charging technologies are still in their infancy, but they no longer may be viewed as science fiction—they require wider investigations in the context of realistic mobile devices and consumer electronics. In this article, we presented the rudimentary physics of DLC conceived for wirelessly power transmission. Then, we summarized and compared its features to those of the other three major wireless charging techniques. We found that DLC is especially suitable for safe mobile applications to provide a charging experience reminiscent of the convenience of Wi-Fi data communications. To demonstrate its usage, we proposed two wirelessly powered network architectures: the fixed DLC infrastructure and the ad-hoc DLC network. Finally, we discussed a range of open issues and future research aspects. DLC constitutes a promising technique, which is capable of facilitating imaginative applications, such as tireless robots in land-based, air-based, and marine scenarios—a truly fertile ground for scientific innovation.

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