Laser vs. Infrared

The question
The question is usually “What are relative advantages or disadvantages of lasers over Infrared for Optical Wireless (OW) systems?” The question is misleading because every laser Optical Wireless system on the market does in fact operate in the infrared part of the electromagnetic spectrum. Usually, the questioner assumes by “infrared” the use of Light-Emitting Diodes (LEDs) as opposed to lasers. The real question is then “What are relative advantages or disadvantages of lasers over LEDs for Optical Wireless systems?”

Infrared
The human eye is most sensitive to light with wavelengths between 400 nm (blue) and 700 nm (red). Any “light” with wavelengths longer than 700 nm is called infrared and is not normally visible (except sometimes as a dull deep red). Devices used for Optical Wireless systems usually operate in the “near” infrared region between 700 nm and 1000 nm. In particular, common Optical Wireless laser wavelengths include 780 nm, 810 nm, 850 nm and 980 nm. Optical Wireless systems using LEDs normally operate between 800 nm and 900 nm. Some advanced laser Optical Wireless systems are operating at the longer wavelength of 1550 nm. The 1550 nm technology was originally developed for use in optical fibre systems and is standard for long range fibre transmission.

LED, laser - brief description
The LED emits light from an extended surface area in almost all directions and over a wide range of wavelengths. It is therefore a multimode, incoherent device and is similar in this way to the filament of an incandescent light. The power efficiency can be near 10%.

In contrast, the semiconductor laser emits light from a very tiny area in one direction and at one wavelength (or a few closely spaced together). It is a single mode coherent device. The power efficiency can exceed 50%. Lasers can be modulated at very high rates (GHz).

Recently, the Vertical Channel Surface Emitting Laser (VCSEL) has emerged. The light from this device comes from a larger surface area than that of the conventional semiconductor laser and is easier to couple into optical systems.
LED, laser comparison for Optical Wireless

Although each device has some advantages and disadvantages, some of these are key to the commercial success or failure of Optical Wireless systems. They are treated below in estimated order of significance.

1. Reliability

The LED is a more reliable and robust device than a semiconductor laser. This is because it uses far lower current densities and lower optical power densities that are far from the stress limits of the materials. The operating device junction temperature is a critical consideration for device lifetime. A few extra degrees can reduce the lifetime by an order of magnitude.

To achieve a long life from a laser in the hot environment typical of a rooftop in tropical climates, it must be actively cooled. Most laser Optical Wireless products do not appear to have cooling, a significant requirement when capable of handling the sustained solar heat loading of the tropical rooftop. The actively cooled laser products may only be viable in moderate climates; the reliability of the cooler is likely then the limiting factor – a thermoelectric (Peltier) cooler consumes a high current.

Another means of increasing the device lifetime is by running it at a lower current with a lower output level. This is very effective with a LED where the output power is a direct multiple of the drive current. However, the laser is much less able to benefit from this technique because it has a threshold drive current below which no light is emitted – unfortunately, the threshold current generates high current densities that reduce the lifetime even when almost no light is generated.

With the PSI Optical Wireless systems using LEDs, a Mean Time To Failure (MTTF) of 25 years or more is estimated even when the system is spending half of its life in hot sunlight in the tropics. Laser Optical Wireless systems probably cannot approach this claim – they may be restricted to a 25 degree C environment. As a consequence, it likely that the maintenance costs of laser Optical Wireless systems in hot climates will be relatively high and that these systems will experience outages caused either by preventive or corrective maintenance.

2. Eye Safety

Although the eye can only see light between 400 nm and 700 nm, the eye is transparent to light with wavelengths well into the infrared beyond 1000 nm. If the eye looks towards powerful sources of invisible infrared light, this will focus down on the retina at the back of the eye, cause local heating to the tissue, and possibly some permanent damage.

Laser light is far more dangerous to the eyes than LED light of the same power. This is because laser light can be focused down on the retina to a very small spot several wavelengths in diameter where the light power intensity is correspondingly great. In contrast, LED light, being from an extended multimode source, cannot be focused down to less than the source area, typically more than 100 micrometers in diameter. For this reason, the potential retinal power
density from a LED source is 3 to 4 orders of magnitude less than that of a laser source of the same power.

Standards bodies such as the IEC and ANSI classify laser sources according to the level of risk. Most laser Optical Wireless products are in a category where direct viewing of the source at close range for extended periods is considered dangerous and viewing using binoculars is dangerous even at extended ranges. Generally, the size of the transmitting lens is selected to be large enough to reduce the laser power density sufficiently to fall within a lower category of risk.

PSI follows the US safety standard ANSI RP-27 for infrared lamps and IEC 60825-1(1998) that applies to lasers and LEDs. When PSI introduces its laser Optical Wireless products, these will likely operate at 1550 nm where there is no risk to the eye retina. Currently, its systems use LEDs operating at 870 nm and are unconditionally eye safe rated Class 1. They can be safely viewed at any range for any length of time with or without binoculars.

3. Atmospheric losses

The range and availability of Optical Wireless systems are limited by atmospheric losses, especially fog. In the absence of fog, the atmosphere is generally clear having a loss of typically 0.5dB/km. However, if one examines the transmission of the atmosphere closely, there are many very narrow high absorption wavelengths, especially when pollutants are there. These have little or no effect on visibility or on LED Optical Wireless systems where the power is spread out over a spectrum about 50 nm wide.

However, if one of these narrow absorption wavelengths corresponds with the wavelength of a laser Optical Wireless system, the Optical Wireless path loss may be significant. Optical Wireless lasers are not normally highly stabilized in wavelength which will drift with operating temperature. Therefore, there is a probability that the laser Optical Wireless system will drift in and out of absorption wavelengths resulting in reduced margins and availabilities.

4. Redundancy and stackability

To increase the amount of transmitter power and provide a soft failure mode through redundancy, some Optical Wireless equipments use several lasers operating simultaneously. However, because lasers are highly coherent devices and are operated at nominally the same wavelength without wavelength stabilization, there will be occasions where two lasers have a wavelength difference so small that an interfering heterodyne beat frequency signal occurs in the receiver within the pass band of the data. This will reduce the margin and availability of the system. A system with four lasers has six such potential problems. This effect does not apply to LEDs because they are incoherent.
5. Beam breakup
The atmosphere is not entirely homogeneous. Scintillation causes distant lights to twinkle. This results from thermal gradients and turbulence within the optical path. These effects can cause different parts of a laser beam to travel slightly different paths and then combine. Because the laser is coherent, the recombination may be destructive or constructive at any particular moment. Typically, the laser beam cross-section profile will break up into dark and light areas changing rapidly with time. This results in recurring momentary losses of signal, degrading the performance of the Optical Wireless link. Being incoherent, the LED is far less susceptible to this effect.

6. Speed
Most commercial LEDs cannot be operated at speeds greater than 155 Mb/s. At this time, Optical Wireless systems requiring greater payloads such as 622 Mb/s and above must use laser sources except over short ranges.

7. Sunlight effects
Diffusely reflected background sunlight degrades the margins of Optical Wireless systems. The sun can cause temporary outages when directly in the field of view of a receiver and there is a risk of permanent damage to devices.

The impact of sunlight can be mitigated by using a narrow band optical filter to pass the Optical Wireless signal but block most of the sunlight. Because the laser has a very narrow spectrum, an optical filter for a laser Optical Wireless system can be much more effective than a filter for a LED Optical Wireless system.

PSI LED Optical Wireless design takes this factor into account to ensure good margins even in the presence of sunlit backgrounds.

8. Antenna size
In principle, laser Optical Wireless transmitters can be diffraction-limited and achieve narrow beamwidths with very small antenna (like a laser pointer). However, for eye safety reasons, near infrared laser Optical Wireless systems do not exploit this potential advantage in order to keep the power density low at the aperture. LED Optical Wireless transmitters must be relatively large to achieve the same beamwidth as that of a laser transmitter.

9. Power consumption
As stated earlier, LEDs are less efficient than lasers and require more electrical power to drive them. However, the power required for a thermoelectric cooler for the laser more than offsets this advantage of the laser.