

Optical Communications: The Next 100 Years

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Over the past few decades, the field of optical communications has produced astounding scientific and engineering feats. In addition, it has helped transform the way society functions since the Internet as we know it could not exist without it. Given the exciting nature of optical science and the ubiquity of communications in our world, there is much reason to hope that this rate of technical progress and impactful applications will continue for many decades to come.

The following predictions might capture the future of our field, or just tickle the imagination.

We know that technological advances have made the transmission of enormous amounts of data across the planet commonplace, with the exponential growth in capacity continuing into the future. Many past advances in transmission capacity have utilized the multiplexing of multiple data-carrying optical waves with each beam inhabiting a unique optical parameter, such as is done with different wavelengths. Although recent research experiments have shown significant capacity increases due to space-division multiplexing, we are just scratching the surface. Basic optical science tells us that the spatial domain has an enormous number of orthogonal spatial states, and we will find new ways to exploit space to enable many orders of magnitude improvement. Whatever the technology, we will have an endless cycle of thinking we have enough capacity followed by the panic of needing more, followed by innovation. We will be feverishly following a Moore's Law-like growth, and always worried that we are coming to fundamental physical limits—but not.

We are always intrigued by the single photon itself. Present single-photon systems are fairly limited in terms of data rate, transmission distance, complexity, and cost. However, utilizing future advances in quantum repeaters and high-speed single-photon sources and detectors, we will be able to control and communicate using single photons for many types of low-power, long-distance, and secure systems.

It is quite likely that advances in the coming decades in the performance and mass production of photonic integrated circuits will enable optics to be ubiquitously deployed wherever and whenever it can bring benefit to the system, just as we use electronic integrated circuits today without thought. Furthermore, optics will bring low-loss and high-bandwidth connections between and within computer chips. Furthermore, with future advances in highly nonlinear devices, optics will perform specific signal processing operations and logic functions alongside electronics to enable higher speed and lower power consumption, such that electronics and optics will be used in a hybridized and harmonized fashion. In some applications, optics will not even need electronics to process data.

Optical networks have enabled many users to communicate with each other very efficiently. However, these networks are still made up of discrete nodes, such that data is sent away from one node and independently received by a different node, without different nodes actually interacting as a single unit. Indeed, think of a computer chip. It is a brain, with many operations occurring in parallel but all working toward a single end goal. With advances in highly accurate optical clocks, networks covering large geographic areas will be designed to act like a large computer brain and synchronously communicate and process data efficiently. Distances will truly disappear.

For the past 100 years, radio has been king of the free-space communications world, with optics barely registering an impact. However, with the constant increase in needed capacity, optical links will become commonplace. Indeed, with the future ubiquity of solid-state lighting, almost any bulb can be used for communications.

Sir Charles Kao, the Nobel Laureate credited with proposing that low-loss glass can be used for a communication system, had said that silica might last 1000 years as the medium of choice. So, going out on a limb, is it possible that silica fiber will give way to a new material with lower loss and lower nonlinearity? Such materials have been envisioned, and the economics may one day demand that a new type of fiber be adopted and laid around the world.

Since there has been exponential growth in the fiber transmission capacity and the demand for that capacity, our field is now cemented as being essential for economic and societal growth. For the past few decades, fiber transmission capacity has increased $\sim 100\times$ every decade. We have seen names fly by—Mega, Giga, Tera, and now even Petabits/sec on a single fiber. Will this continue? In 100 years and if—a big “if!”—advances continue at the same pace, we will see words like Exa, Zetta, Zotta, and even Brontobits/sec (10^{27} bits/sec). It is thrilling to imagine the enabling technologies and potential applications for such capacity.

If past is prologue, either the above-mentioned or other transforming advances will occur. If this happens, the exponential growth in the capacity of communication systems will enhance our ability to interact with each other, our environment, and machines in unforeseen ways.