Optical wireless may be the answer to dropped calls, and more

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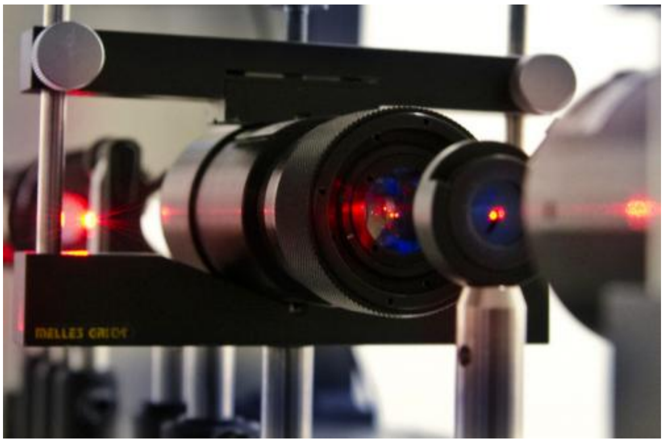

A demonstration set-up in Mohsen Kavehrad's lab creates partially coherent visible (red) light. This type of light performs better through the atmosphere than pure coherent light, an important consideration for outdoor optical wireless applications. Credit: Patrick Mansell

Anyone who has tried to make a cell phone call from a crowded football stadium has had a taste of what engineers call spectrum crunch.

Can you hear me now? Uh, no, actually. Not so much.

The looming problem, and the reason for all those dropped calls, is that there's not enough bandwidth to accommodate the exploding use of wireless mobile applications.

"The first wireless mobile users in this country were police and taxicabs talking to dispatchers," explains Mohsen Kavehrad, W.L. Weiss Chair Professor of Electrical Engineering at Penn State. "It was set up for emergency services." Now there are some five billion cell phones and an additional two billion wireless devices in use worldwide, and those numbers swell every year. And with more and more data-handling power—particularly the ability to download video—those devices require many times more bandwidth than ever before.

The result, Kavehrad says, is saturation: far too many transmissions over the same narrow frequency band. And that means signal interference on a massive scale. In 2013, for the first time, the Federal Communications Commission projects a "spectrum deficit" due to the phenomenal growth of mobile data traffic, and that deficit is expected to triple in 2014. Nor does the genie show any signs of climbing back into the bottle.

"Once people have tasted wireless, it's such a sweet solution, they're not going to go back," Kavehrad says. "This is an engineering problem we need to solve."

That's the philosophy behind the Center for Optical Wireless Applications (COWA), a National Science Foundation-funded collaboration between Penn State and the Georgia Institute of Technology, formed in 2012. As one of NSF's Industry/University Cooperative Research Centers, COWA actively seeks partnerships with industry to develop a new generation of wireless alternatives. Kavehrad, an industry veteran who worked at GTE and Bell Labs before coming to Penn State in 1997, is the center's director.

The optical option

Among the potential solutions to spectrum crunch, one option would seem to stand out. If the current bandwidth allocated for mobile applications—a total of about two measly gigahertz scattered through the radio wavelength—is getting too crowded, why not just move up the dial to higher frequencies?

The problem, Kavehrad says, is that transmissions at higher frequencies don't travel as far or survive as long bouncing off ridges and buildings. Engineers call it path loss, and it leads to weaker signals. The fall-off is incremental, Kavehrad says, but once you get above four gigahertz in the microwave band, grabbing a good signal requires an unobstructed line-of-sight between sender and receiver. That's why the GPS device in your car needs to be fixed right under the windshield: It depends on a satellite that transmits in the UHF band. Without a direct line-of-sight, you're on your own.

"But think of how many apps we have like that," Kavehrad says. "You're sitting on a plane in a close environment. You're sitting in a Starbucks, sipping a coffee. There are lots of existing Wi-Fi services that could move up to frequencies that require line-of-sight. In these situations, do we really need to be in the two gigahertz of band that can be used for mobility?"

If the answer to that question is no, then a whole new world of bandwidth opens up at the high end of the spectrum. And the higher you go, Kavehrad says, the more bandwidth is available. "So if I have to rely on line-of-sight," he says, "I might as well go to extremely high frequency. I might as well transmit using optical wavelengths: infrared, or even visible light."

It isn't a new idea, he adds. Alexander Graham Bell's photophone, patented in 1880, some 15 years before Marconi's wireless radio, took sunlight, modulated it mechanically, and used it to carry human speech. And of course today's vast fiberoptic communications networks are based on pulsed light transmitted via glass fibers. Optical wireless technology, Kavehrad notes, is based on the same principles, except that the data-laden beams of light are transmitted through the air.

Intelligent light

Engineers at IBM Zurich in Switzerland built an optical wireless system in the early 1980s, but with the Internet still nascent, there was not enough demand to develop the idea, and the technology languished. By the time wireless did take off more than a decade later, the radio frequency was well-entrenched as its carrier, and the telecommunications industry was reluctant to walk away from an established technology.

Now, however, with mobile data traffic doubling every year and the threat of service breaks looming, optical wireless again looks like a promising alternative. A critical boost, Kavehrad says, comes from a new generation of high-intensity light emitting diodes, or LEDs.

Once limited in both power and commercial appeal, LEDs have been transformed over the last 10 years by advances in materials science and manufacturing. They're still relatively expensive up front, but in addition to being many times more energy efficient than incandescent lights, they are safer than fluorescent lamps. More importantly for optical wireless technologies, "these are solid state devices, which means they can be modulated, or coded with digital information," Kavehrad explains. Today's LEDs can switch on and off thousands of times per second, much faster than the human eye can perceive. Using LED technology, many manufacturers now make "intelligent" lightbulbs that can sense human presence and adjust their intensity accordingly.

"There are millions of applications coming out of this," Kavehrad says. "In addition to lighting, LEDs can be used for communications, sensing, even navigation."

Demonstrating one such possibility, he and graduate students Zhou Zhou, Weizhi Zhang, and Sakib Chowdhury, working with colleagues at South Korea's Hallym University, recently developed a positioning method based on proximity, a hybrid system that combines LEDs with a conventional wireless network into a kind of indoor GPS helpful for finding items or people in large stores, museums, and hospitals.

This LiFi system relies on overhead LED light fixtures, each assigned with a location code, linked with short-hop radio frequency transmitters spaced throughout the building. Because the light from the LEDs does not penetrate walls, the radio frequency transmitters are needed to carry the signal from room to room.

Here's how it would work in a large department store or mall: A computer at the entrance, accessible by keyboard or smartphone, contains a database of all the merchandise inside. Each item is tagged with a cheap, low-volume radio transmitter. When queried, the computer signals a nearby transmitter that relays the signal hop by hop until it reaches the item sought, which is illuminated by an LED. The transmitter on the item's tag reads its location from the overhead LED and sends the information back through the network to the computer, where it appears on the display screen to aid the harried shopper.

Beam us up

Kavehrad envisions many other possibilities for optical wireless technology. Already, a handful of European towns are using smart streetlights that turn on only in the presence of cars or people. "Why not incorporate car headlights that communicate with traffic lights, or with roadside billboards for stores and other businesses?" he asks.

For indoor delivery of wireless broadband data throughout homes and offices, Kavehrad notes, optical wireless networks offer several advantages. In addition to helping to alleviate spectrum crunch, optical systems are potentially much faster than conventional Wi-Fi. And because light cannot pass through walls, they are also more secure.

In a 2007 article in *Scientific American*, Kavehrad described a local-area network that uses infrared light to connect multiple users in an office workspace. A transmitter/receiver fixed to the ceiling beams coded infrared light to laptops and other devices throughout the room fitted with similar transmitter/receivers. Because the signal is diffuse and reflects off surfaces to scatter around the room, partitions and barriers don't impede it.

Such systems are already in use, Kavehrad writes, but tend to be plagued by what he calls echoes, caused by the scattered signals arriving at a receiver at slightly different times. To alleviate this problem, Kavehrad envisions optical filters for both transmitter and receiver.

A 2010 article in MIT's *Tech Review* reported on yet another milestone. In a lab demonstration, the journal reported, Kavehrad and his students, using an infrared laser focused on the ceiling and a modified photo detector, had achieved a transmission speed of one gigabit per second—several times faster than the fastest Wi-Fi network. "This probably will be the next generation wireless communications technology," commented Zhengyuan Daniel Xu, an optics researcher at the University of California at Riverside.

Kavehrad and others are now working on systems that transmit via visible light, using LEDs. Such systems take efficient advantage of the ubiquity of overhead lighting. One indoor environment particularly suited to this visible light communication, Kavehrad says, is the cabin of a commercial airliner.

"If you get on a plane that is less than five years old, the lights are all LEDs anyway," he notes. As part of a research agreement with Boeing, one of its industrial partners, COWA researchers at Penn State are exploring LED-based systems that could replace Wi-Fi and be used cabin-wide for everything from mood lighting to crew-to-passenger communications to in-flight entertainment.

"This is the type of real-world problem we are set up to address," Kavehrad says. "The whole purpose of these cooperative centers is to create a bridge from academic research to commercial application.

"It's a long cycle from demonstration in an academic lab to adoption by industry," he adds. "But these are technologies that are strategically and economically important. You have to have the patience and vision to do this. And we do."

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