tennas, in particular analyzing the possibilities of dynamic reconfiguration across a wide range of frequencies.

Such reconfigurability could allow graphene antennas to save power and limit interference, as well as perform highly targeted sensing.

"We are very excited because we can tune the electrical antenna properties of graphene with a DC voltage," says Burke. By changing the sheet resistance, his team has been able to lift the impedance of a graphene nanoantenna—something not possible with other kinds of nano-antennas.

In a recent paper, Burke's team proved that graphene could function over a broad frequency range—at DC, 10GHz, 100GHz, and 100GHz–1.5THz in a single sweep. The team was able to measure the graphene sheet's impedance with a novel spectrometer built by Elliott Brown at Wright State University in Ohio. Recently, the team has built on this work to tune the graphene antenna across the entire band from 100GHz to 1.5THz.

Given these physical limitations, researchers are focusing on scenarios that would benefit from placing nanoantennas and transmitters in close proximity to each other, to create what Akyildiz describes as "an Internet of nano-things."

At the most pedestrian level, such a network could offer hope of speeding up the "last mile" bottleneck that bedevils so many everyday Internet connections: the humble wireless router. For all the much-heralded advances in network speeds over the past few years—FIOS, Terabit Internet, and IPv4, to name a few—many of us have yet to see the full promise of these advances, thanks to the speed limits inherent in the 802.11n standard that most wireless routers follow.

A full-fledged nanonetwork could go much further than replacing old Wi-Fi routers, however. It could also, in theory, harvest vibrational or electromagnetic energy from the environment to reduce power consumption.

Looking further ahead, researchers are also starting to imagine long-range applications of highly miniaturized antennas. "Imagine what you could do if you could build a radio that could fit inside of a single cell?" asks Burke, whose team is now exploring the possibility of graphene nanoantennas that could bind to DNA.

Burke's team is working with Ned Seeman at New York University and Michael Norton at Marshall University, both of whom have done extensive work with DNA "origami," to explore the possibilities of nanoscale networks for DNA sensing. If successful, this initiative could bring graphene nanoantennas closer to the world of biochemistry.

As intriguing as some of these ideas may seem, the practical challenges remain daunting. At the most fundamental level, nanoantennas cannot work by themselves without additional components such as nanotransmitters and nanoreceivers—neither of which exist yet. Akyildiz's team is currently applying for patents for graphene-based nanotransmitters and nanoreceivers.

In the meantime, several other teams around the world are pursuing related ideas for graphene-based antennas and related devices. While the early results are promising, the real work is just getting under way.

"We have one idea about nano-antennas, but there are other people with other ideas about nano-antennas," says Akyildiz. "It is a race."

Further Reading

Akyildiz, I. F. and Jornet, J. M.
The Internet of Nano-Things. *IEEE Wireless Communication Magazine*, vol. 17, no. 6, pp. 58-63, December 2010.

Burke, P. J., Li, S., and Yu, Z.
Quantitative Theory of Nanowire and Nanotube Antenna Performance. *IEEE Transactions on Nanotechnology*, 5(4), 314-334 (2006).

Perruisseau-Carrier, J.
Graphene for antenna applications: opportunities and challenges from microwaves to THz (invited). Loughborough Antennas & Propagation Conference (LAPC2012), UK, 2012.

Rouhi, N. et al.
Broadband Conductivity of Graphene from DC to THz, *Nanotechnology (IEEE-NANO), 2011 11th IEEE Conference on* , vol., no., pp.1205,1207, 15-18 Aug. 2011doi: 10.1109/NANO.2011.6144485 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6144485&isnumber=6144287

Alex Wright is a writer and information architect based in Brooklyn, NY.

ACM Member News

LOVE OF SOLVING PROBLEMS SPURS YELICK ON PROGRAMMING

A love of using computational solutions to solve problems is what inspired Katherine Yelick, professor of computer science at the University of California, Berkeley (UC Berkeley), to help develop the Unified Parallel C (UPC) and Titanium programming languages. "I love designing programming languages to make computers, particularly supercomputers with parallelism, less expensive and easier to use," Yelick says.

Yelick and UC Berkeley Electrical Engineering and Computers Sciences chair David Culler co-invented UPC in 1996; the Titanium language soon followed. Yelick has demonstrated the languages' applicability across architectures using novel runtime and compilation methods. She also co-developed techniques for self-tuning numerical libraries, including the first self-tuned library for sparse matrix kernels, which automatically adapts code to properties of the matrix structure and machine.

Yelick's proudest accomplishment is the recognition of her work on Partitioned Global Address Space Languages (PGAS), which lets users read/write data anywhere in the system and incorporates partitioning for accelerated communication.

"Twenty years from now, I hope programming languages better hide complexity in supercomputers, and that it will be easier to write good programs," Yelick says.

Meanwhile, Yelick is collaborating with her husband and UC Berkeley colleague Jim Demmel on a paper called "Communication-Avoiding Algorithms." Says Yelick, "Avoiding communication is not the right model for marriage, but it is great for parallelism, where communication slows you down."

—*Laura DiDio* is principal at ITIC, a Boston IT consultancy.