# Making massive MIMOs

Massive arrays of miniature graphene antennas are set to enable high speed short range communications in the terahertz spectrum. By **Graham Pitcher**.

The communications issues related to the Internet of Things have been discussed over the last few years and a range of solutions is available, although some remain proprietary.

But a new set of challenges is emerging as designers look to enable communications between devices taking advantage of nanotechnology. In the words of Ian Akyildiz, pictured below, professor of telecommunications at Georgia Tech in the US: "We're now talking about the Internet of Nanothings." And the research is being enabled by graphene.

"I first had the idea about nanoscale communications in about 2006," he said, "but I thought the only way nanoscale machines could communicate would be through biology. But my PhD student Josep Jornet said we should look at electromagnetic means and we realised we could enable this in the THz band – and we found graphene."

### Transmitting at more than 1Tbit/s

Jornet started to explore how graphene could be used to create antennas and, between them, the team had success in its first year. "We validated performance, presented the concept at a conference and applied for a patent," Prof Akyildiz noted.

What graphene enabled was an antenna that supported data rates in excess of 1Tbit/s, but only over distances of up to 1m. "That's impractical for many applications," he added.

Jornet, now an assistant professor at the State University of New York (SUNY), said that graphene has extraordinary properties when it comes to its use in antennas. "The most important thing is that it supports the propagation of surface plasmon polaritons and this is the key property that enables the development of small, efficient antennas.

"Plasmons – surface confined waves – exist in other materials," he continued, "but generally at optical frequencies. This is the first time it has been achieved at the low end of the terahertz spectrum."

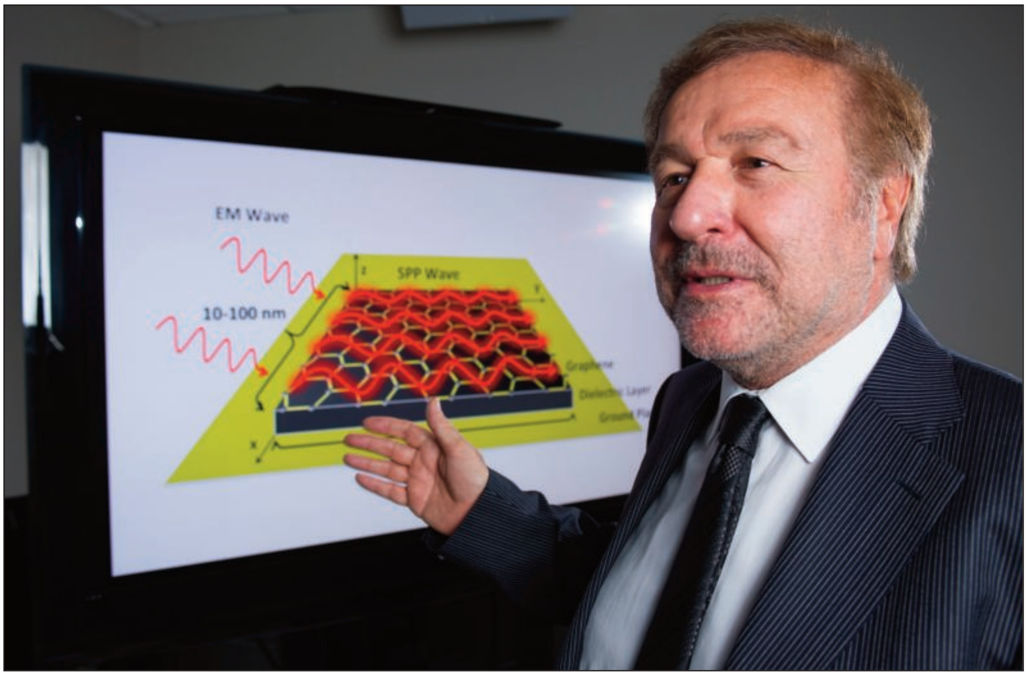
***"Our project shows the concept of graphene based nano antennas is feasible."***
Prof Ian Akyildiz

"When electrons in graphene are excited by an incoming electromagnetic wave, they start moving back and forth," Prof Akyildiz explained. "Because of graphene's properties, this global oscillation of electrical charge results in a confined electromagnetic wave on top of the graphene layer."

It would be possible to take advantage of plasmons in metals such as silver and gold, but this would mean devices operating at hundreds of THz. "While those frequencies might offer advantages in communication speed," Prof Akyildiz, pointed out, "their range would be limited by propagation losses to just a few microns." And copper is ruled out because it doesn't support plasmons.

The nano antenna developed by the Georgia Tech team, working with researchers from SUNY, comprises a layer of graphene on a dielectric and a ground plane. "The graphene must be on top of a dielectric, such as gallium arsenide," Prof Akyildiz said. "Metallic antennas don't need this extra layer. It's not like we have taken a classical design and used graphene; there's a lot of IP involved in our antenna."

While the team is working on single



graphene antennas, their research holds out the prospect of something far more exciting – ultra massive MIMO antennas. Prof Akyildiz noted that the concept of MIMO antennas – many inputs, many outputs – emerged about 10 years ago.

"The first such devices were 2 x 2; now, it's up to 64 x 64 and the approach is in the plans for 5G. But it has to be limited to small numbers – perhaps 100 x 100 – because you need a certain spacing between each antenna to avoid interference problems. But how much space is there in a small phone for a 100 x 100 MIMO?" he asked

### Ultra massive MIMO antennas

Jornet added: "There has been much talk about massive MIMOs, but they are more likely to be used in basestations; we're talking about using them in a mobile phone. When we work with graphene, we can make things smaller and put them closer together. We may be able to create a 1k x 1k MIMO and put it anywhere."

Prof Akyildiz says 1024 graphene nano antennas can be created in an area of about 1mm$^2$. "Plasmonic nano antenna arrays exhibit high gain, which can help us to increase the communication distance at THz frequencies," he said. "For example, a 1k x 1k beamforming set up can provide a gain of about 80dB; enough to establish a 2Tbit/s link at 10m when transmitting at 1THz – more than two orders of magnitude better than any existing standard."

Transmission distance, however, remains a challenge. "The atmosphere affects signal propagation at higher frequencies," Jornet noted. "However, there are windows that allow longer distance transmission. We have ideas for distance aware modulation techniques and may be able to transmit over 50m, but we're still looking for more."

But the ultra massive MIMO array is, for the moment, a concept. "We have developed analytical and simulation models," Prof Akyildiz continued. "Fabrication and experimental validation will follow in the near future."

"Our project shows the concept of graphene based nano antennas is feasible, especially when taking into account very accurate models of electron transport in graphene," he concluded. "Many challenges remain, but this is a first step toward creating advanced nanomachines with many applications in the biomedical, environmental, industrial and military fields.

"It may take another couple of years, but but they could change the entire communications paradigm because they're so tiny."

However, one other problem remains to be solved: the cost of graphene. Jornet said: "We can use small samples of graphene in the lab; enough to make an antenna and transceiver. We're hoping the materials people can reduce the production cost so our antennas can be mass produced."

### Printable antennas may bring low cost and flexibility to a range of applications

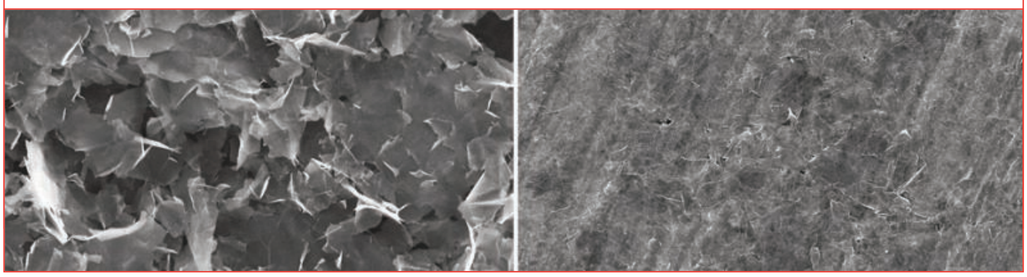
Researchers from the University of Manchester have used compressed graphene ink to print an RF antenna measuring 14cm x 3.5mm onto a piece of paper. According to the team, the antenna performed well enough to make it practical for use in RFID tags and wireless sensors.

Graphene ink is usually made by mixing graphene flakes with a solvent, and sometimes a binder. Graphene ink with binders usually conducts electricity better, but only after the binder – an insulator – is broken down by annealing. But this high temperature process limits the surfaces onto which graphene ink can be printed.

The team found that by printing and drying the ink, then compressing it with a roller, graphene's conductivity was increased by more than 50 times.

Researcher Dr Zhirun Hu said: "What makes printed graphene attractive for antenna applications is its ultra low cost and flexibility and the fact that it can be printed on any substrate without needing a high temperature process. We can use screen printing to produce graphene antennas, which suits low cost mass production."

Expanding, Dr Hu noted: "Being able to print antennas on any substrate means we could see a disruptive technology for low cost, wearable communications products. In addition, we'll be able to print a complete RF transceiver in the near future."



Electron microscope images show the graphene ink after it was deposited and dried (left) and after it was compressed (right)

### Tunable graphene antenna

Europe funded Project Nano RF has demonstrated a graphene antenna that operates in the microwave spectrum and which can be tuned using an external voltage. The antenna is less than 1mm thick, with a diameter of 100mm, which makes it one of the smallest such devices.

According to the researchers, the main application for the antenna will be in RF communications, where its tunability will allow switching of communication channels.