ane, the molecules can become trapped inside. Most of the molecules that researchers would like to ferry into cells are larger than methane, however, and so the team is working on larger capsules—already dubbed "molecular softballs"—that have the same simple structure.

Rebek admits that harnessing the new structures to carry drugs is something of a dream, but the researchers are taking steps toward realizing it. In one line of research, they are looking for ways to trigger the release of the spheres' contents at the required time. One scheme entails attaching carboxylic acid groups to the outside of the spheres. If a sphere's surroundings become more alkaline, the acid groups are converted to negative ions; the charges repel each other, bursting the sphere open and releasing the contents.

Rebek isn't stopping there, however. He thinks that, for maximum effect, an artificial virus should, like a real virus, carry a self-replicating molecule, something that Rebek has worked on extensively in the past (*Science*, 22 May 1992, p. 1179). Such a molecule, once released inside the cell, could use the cell's raw materials to copy itself. If the self-replicating molecule were also a drug, the result would be a much higher dosage than could be achieved by simply trying to smuggle the drug through the cell membrane.

Stoddart isn't sure the analogy between viruses and molecular tennis balls can be pushed that far. But he applauds the spirit: "Chemists are beginning to see how the concepts of biology, such as self-assembly and self-replication, can be transposed to chemistry."

–David Bradley

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OCEANOGRAPHY

Dialing Up Undersea Data—Long Distance

In the deep waters off the California coast, around the submerged faults that make up Monterey Canyon, oceanographers this winter deployed a trailblazing underwater research system. At first glance, it includes just a few ocean bottom seismometers, current meters, temperature and pressure sensors—nothing out of the ordinary. But each of these traditional research instruments also contains a state-of-the-art underwater "acoustic modem," which can detect and bark out digital information, sending it surfing along sound waves that slice through the ocean. And by doing so, these modems could very well bring about a sea change in the way oceanographers work.

Those sound waves can carry data from the instruments to a surface buoy, which then relays it via radio waves to onshore computers. As a result, instead of sending ships out to recover instruments—a time-consuming, expensive effort that may yield nothing if the instrument has broken down—land-based scientists can continuously eavesdrop on their bottom-dwelling instruments, retrieving data at near real-time speeds. Investigators can even interact with their experiments, increasing data collection if events such as an underwater eruption occur. These are options researchers never had before. "The acoustic modems are a great idea. We see the whole oceanographic community needing them," says Steve Etchemendy of Monterey Bay Research Aquarium Institute (MBARI), which operates the Canyon network.

Ultimately, the modems may help ocean scientists address what some call one of the most fundamental problems of the field: the "ocean sampling problem," which is an inability to monitor the world's waters comprehensively over large distance and periods of time. Until now, scientists have been limited to relatively brief glimpses of the ocean from research vessels and short-lived instruments. But one day, in the words of engineer Josko Catipovic of Woods Hole Oceanographic Institution (WHOI), acoustic modems will provide a "global underwater cellular network." This novel idea will allow oceanographers to give early warning of deadly tsunamis, watch video images of marine animals and mid-ocean ridges, do long-term environmental monitoring of dumpsites and sunken nuclear subs, and control autonomous research vehicles—all from dry land.

That optimistic vision has already attracted generous developmental funding from a host of federal entities like the Advanced Research Projects Agency (ARPA), the Office of Naval Research (ONR), and the National Science Foundation (NSF), which is sponsoring Monterey's prototype network. Other projects garnering government interest are proposed arrays of modem-equipped instruments around the Juan de Fuca Ridge off Seattle and in the Labrador Sea, the latter to study Arctic water flowing into the Atlantic. There are, of course, still a few waterbugs in the systems,-chief among them the reluctance of many oceanographers to trust their experiments to new technology whose long-term reliability has not yet been proven. The allure of the technology, however, is very powerful, because researchers have long coveted this type of remote communication.

Chatting across large stretches of water is a formidable task. The ocean effectively scatters electromagnetic radiation, making communication with most radio waves or lasers feasible only for short distances. That leaves sound waves, which can punch through water for miles. Acoustic modems generate these waves by converting digital data into electrical signals that vibrate a metal plate, like a stereo's tweeter. These devices also have receivers that capture acoustic waves and reverse the process.

Underwater acoustic communication dates back at least to the 1950s, but until recently it has been hampered by a phenomenon called multipath, which is particularly troublesome in shallow coastal water, undersea canyons, and other places of great research interest. Multipath is caused by acoustic waves bouncing off the sea floor, the ocean surface, and even layers of water at different temperatures, which produces confusing echoes that arrive seconds apart. "The reverberation is so bad. It's a very nasty problem," says Northeastern University electrical engineer David Brady. Primarily because of that, sea acoustic links were limited to low data rates—"speaking" slowly to avoid confusion from the echoes—and even then useful only in low-echo conditions, such as in the deep ocean.

That limitation left oceanographers stuck with their two traditional research methods, neither of which made them very happy. Scientists could adopt what might be called a dump and pray strategy, where experiments that record data internally are dropped off a ship and picked up days, weeks, or months later. This approach is restricted by the amount of data each device can store, as well as by all-too-frequent equipment failures. "There's been more than one experiment that when you fetched it, there had been a malfunction and you lost a year of data," laments Massachusetts Institute of Technology (MIT) ocean engineer Arthur Baggeroer. Alternatively, ship-based oceanographers can study the ocean with submersibles or towed instrument arrays. Not only is this expensive—an oceanographic research vessel might cost $15,000 a day to operate—but the data only describe the ocean when and where the ship was.

In the late 1980s, thanks largely to low-cost digital signal processing hardware, modem technology—and their data rates—sped forward. Engineers could construct, with just a few integrated circuits, acoustic modems that filtered out signals from noise and even took advantage of the multipath nuisance, using the late-arriving echoes to check the accuracy of the original signal. Investigators also developed new techniques for encoding data on sound waves, strategies that allowed higher data rates and yet demanded much less power. That latter is of paramount importance for instruments intended to work for months or years on the seafloor.

In the last few years, Catipovic, Brady, and their colleagues have been testing their new modems out in a variety of environments, ranging from the very shallow waters of Massachusetts' Buzzards Bay to deeper sites off Bermuda. Even in acoustically hostile regions plagued by multipath, their instruments can now send data more than 200 kilometers at 2000 bits per second. At much shorter ranges, 1 to 10 kilometers, they can reliably increase that rate to more than 30,000 bits per second, which is just fast enough for low-resolution camera images.

That's opened up an underwater world of possibilities. In the Monterey network, which is capable of handling the data flow from more than 250 instruments, one group is starting to develop a tsunami warning system. Using sea floor pressure sensors that reveal ocean swells above, researchers at the National Oceanic and Atmospheric Administration's (NOAA) Pacific Marine Environmental Laboratory in Seattle have observed the rare but deadly full-fledged tsunamis caused by strong earthquakes beneath the oceans, as well as the much smaller "mini-tsunamis" that might create waves only 1 centimeter high. In the past, they could only study these events long after they occurred. "To get the data, you would have to recover the instrument. That's just a rip-roaring pain in the neck," says NOAA engineer Hugh Milburn.

That's also much too late to warn people on shore. Now, by monitoring a modem-equipped pressure sensor in Monterey Bay, the NOAA group has proven they can catch mini-tsunamis—and presumably their deadlier counterparts—in the act. (And a network of modem-equipped ocean bottom seismometers would make identifying the causative quake's epicenter a breeze.) NOAA tsunami researcher Frank Gonzalez and his colleagues are now seeking money for an array of acoustically linked sensors that would be placed around the Pacific Rim at sites known to exhibit tsunami-producing tectonic activity, such as areas off the coast of Alaska. "We'd be taking a research instrument and turning it, with an acoustic modem, into a functional reporting system," Gonzalez says.

Reporting, however, is only one part of communication, and sending commands back to an instrument may be as important as receiving its data. There are many experiments, such as those situated near hot undersea vents, "where if you had known something was happening, you would have sped up data collection rates. With a modem, we'll actually be able to react," MBARI's Etchemendy notes.

Two-way communication isn't limited to immobile instruments, and the new modems may start to take the word "autonomous" out of autonomous underwater vehicles (AUV). This small but growing class of research submersibles is designed to operate without a power or communications tether. They've largely been on their own until now, but if all goes as planned on 1 April, researchers will drop a modem-equipped submersible, built by James Bellingham and his colleagues at MIT, through a hole in the Arctic icepack so that it can map out the underwater ice surface. Distributed in ice around the site will be a half-dozen acoustic network nodes that can communicate via radio to controllers and via sound waves to the swimming vessel. It will be the first test of whether this technology can help guide the navigation of a moving vehicle—a tricky task considering there will be a 5 to 10 second delay response. Even with that, Bellingham believes acoustic control might save his AUV from being lost at sea when one encounters something unexpected. "It would be awfully nice to talk to it. Almost any failure now is fatal," he says.

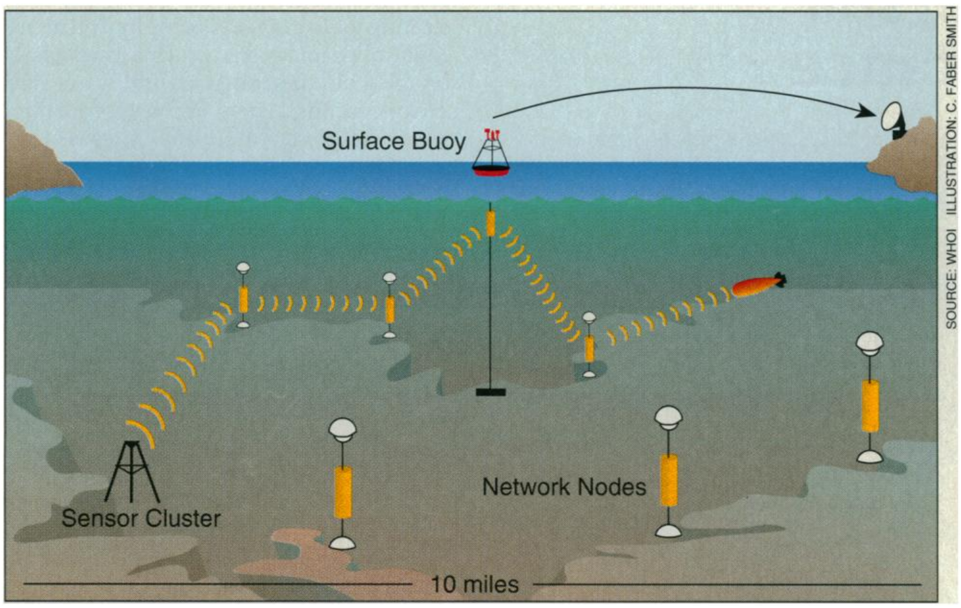
Investigators envision more than just guiding AUVs. Patrolling submersibles, constantly sending back data, would make regular surveys of mid-ocean ridges, ocean dumpsites, or sunken subs. If something unusual occurred, such as an unexpected radioactivity release, investigators would know within minutes. Some engineers at WHOI even believe they will one day acoustically guide manipulator-equipped AUV's through tasks like collecting samples.

Acoustic modems may also go beyond guiding scientific probes to actually become such probes themselves. Physical characteristics of the surrounding water—salinity, pressure, and temperature—largely determine the multipath phenomenon by changing the speed by which various echoes propagate. In August, says Catipovic, there are plans to deploy an array of acoustic modems in shallow coastal water, all talking to one another. From analysis of the multipaths, scientists should be able to discern data such as a temperature profile of the region. "As a side affect of transmitting, you can learn about the ocean," says Catipovic.

Despite all these ambitious plans, engineers admit the new technology is having some trouble conquering the hearts of ocean researchers, who are reluctant to trust their delicate experiments to fancy and largely untested gadgets, which still carry a hefty price tag of $10,000 each. For instance, although the Monterey network is capable of handling many more instruments, less than a dozen are online. "It's very hard to jar scientists into doing science a new way," says Catipovic. That's no surprise for a community that was slow to embrace the use of a manned submersible like *Alvin*, he says.

Yet those who have actually worked with the modems, such as Thomas Curtin of ONR's arctic science office—which is sponsoring the ice-mapping effort—say that scientists will come around, given proof of reliability, lower costs, and even faster data rates. There's no need to oversell acoustic modems, he told *Science*: "I think it's a revolutionary technology. At a certain point, it will take on a life of its own." If so, amidst the bellows of whales and the clicks and whistles of dolphins, oceanographers will increasingly hear the sweet sound of data.

–John Travis



Under and out. A network of acoustic modems can relay data from underwater sensors back to the surface, as well as monitor and control an unmanned research submersible.