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Underwater networking

Captain Nemo goes online

Networking: Emerging undersea data networks are connecting submarines, aquatic drones and other denizens of the deep

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DURING the Cuban missile crisis of October 1962 the Soviet Union stationed submarines in the region in order to be able to sink American ships in the event of war. But communication between the submarines and Soviet high command was hard. Electrically conductive salt water absorbs radio waves, so exchanging information with Moscow required the submarines to ascend to periscope depth in waters patrolled by American planes and ships. Between scheduled transmissions Soviet crews also poked antennae out of the water and listened to commercial radio to see if hostilities had broken out. A blunder could have been catastrophic, says Alexandre Sheldon-Duplaix, a naval-warfare historian at France's defence ministry, because the Soviet submarines were armed with nuclear torpedoes that the West did not even know existed.

In the decades that followed navies continued to be dogged by the difficulty of establishing underwater data links. In the 1980s America decided not to integrate its new "Los Angeles" class of attack submarines with aircraft-carrier groups, says Norman Friedman, a former consultant to the secretary of the US Navy, because it was concerned that flaky communications links between ships and submarines might lead to collisions or friendly fire. A former commander of an American carrier in the 1990s says he was unable to establish submarine contact "more times than I can even remember". But now better underwater-communications technologies are changing the rules.

Although traditionally more a “sneaky sniper” than a team player, as Eric Wertheim, an American naval analyst, puts it, submarines are increasingly expected to co-ordinate with surface and land forces. Subsea networks being developed by America and its allies will shuffle data between submarines, aquatic drones and sensors via devices that sway beneath the water or bob on its surface. They will make it possible to detect enemy vessels and mines and allow submarines to link up with surface ships, aircraft and distant command centres, says Vernon Clark, America’s former chief of naval operations. Undersea networks could also monitor waterways and gather scientific data.

Making waves

In the 1970s and 1980s both America and the Soviet Union built underwater-signalling systems based on “extremely low frequency” (ELF) radio waves. Both systems needed large electrodes, buried in the ground 50-60km apart, and could then send signals to submarines thousands of kilometres away—but only one way, and at a rate of around ten characters per minute. To overcome these limitations, more recent research has focused on signalling using sound, over shorter ranges.

The big technical challenges have been mostly overcome, says John Potter of NATO’s Centre for Maritime Research and Experimentation (CMRE) in La Spezia, Italy, who heads one of several groups building underwater networks based on small devices called acoustic nodes. These could be “shovelled out of a plane”, says Mr Potter, to provide the military alliance with an unprecedented ability to gather intelligence, communicate and co-ordinate its forces underwater. Akin to mobile-phone towers but communicating using pulses of sound rather than radio waves, the nodes are placed a kilometre or so apart. A few extra nodes are needed because acoustic signals can be scrambled or lost near a choppy surface, in fast currents or in a region with a sharp temperature change.

Each node, which costs $5,000-10,000, is around the size of a canister of tennis balls. It contains a computer to process signals, a microphone to pick up sound waves, and a piezoelectric transducer to emit them. This transducer, similar in size to a small plate, is made of a special material that expands and contracts suddenly when a voltage is applied, creating an acoustic wave in the water. This signal is picked up by other nearby nodes, which retransmit it as appropriate to more distant ones, like an underwater internet.

Seaweb, an underwater network being designed at the Naval Postgraduate School in Monterey, California, and the Space and Naval Warfare Systems Command in San Diego, takes a similar approach. Its nodes have been tested under the Arctic ice sheet and in water 300 metres deep. Data packets hop from one node to another until they reach their destination—a submarine, a subsea drone, a warship or a “gateway” node at the surface. Gateway nodes use a satellite-radio link to connect the underwater network to the rest of the world.

Seaweb nodes are capable of exchanging information through dozens of kilometres of water. Such long ranges, however, require the use of low-frequency sound waves, which reduces the data rate. Joseph Rice, the project's leader, says a Seaweb node can send a low-resolution photo to another one 5km away in five seconds—two seconds to emit the sound waves, and another three for them to travel that far. In seawater acoustic waves carry only a few thousand bits of data per second, but they travel at 5,600kph (3,500mph)—five times the speed of sound in air.

It is hardly broadband, but it can be used to connect submarines and warships to sensors and roving subsea drones, also known as unmanned underwater vehicles (UUVs). Mr Rice imagines that UUVs might deploy sensor nodes and could visit them when required to download the data they have collected in large quantities. Sensors could also alert UUVs of any unusual readings that require investigation.

In a related project, called NILUS, Norwegian researchers have designed a combination of acoustic and magnetic sensors capable of detecting submarines in deep water. Roald Otnes, project scientist at the Norwegian Defence Research Establishment, says the nodes are easy to deploy: each one is simply heaved overboard (it weighs about 60kg, thanks largely to its battery pack). The NILUS sensor nodes are networked using technology provided by the Seaweb team, which is also helping a Singaporean project called UNET.

The shallow offshore waters around Singapore, where container ships and snapping shrimp create a racket, present a particularly difficult environment for acoustic signalling, but UNET nodes manage to communicate at distances of more than 2km. Equipment that performs well around Singapore will work pretty much anywhere, says Mandar Chitre of the National University of Singapore, the project's leader. A handful of bobbing surface nodes provides a link to the Singaporean mobile-phone network.

A separate European Defence Agency effort called RACUN brings together Germany, Italy, the Netherlands, Norway and Sweden. Such co-operation illustrates a desire among NATO countries and their allies to design technologically compatible subsea networks that could be interconnected. Unfortunately, makers of acoustic nodes have developed several incompatible data protocols, creating a “Tower of Babel and a world of pain” for teams trying to link them together, says Mr Potter.

Data rates have steadily improved, increasing tenfold over the past two decades, says Michele Zorzi of the University of Padua, in Italy, who is busy extending the RACUN system so that nodes can handle multiple messages simultaneously. The improvement in bandwidth is largely due to progress in signal-processing software, which is capable of coping, for example, with multiple echoes of a signal from a choppy surface. The latest nodes can also save bandwidth by deciding for themselves how much to compress an image, say. But smarter software is needed, says Arto Laine, manager of underwater-warfare research at Patria, a Finnish defence contractor. Even with an excellent acoustic link, a mine-hunting UUV cannot stream all the data it collects to a submarine or surface node. So UUVs will have to get better at determining what information should be sent back first, he says.

A growing understanding of bubbles caused by surface waves, which affect how far acoustic signals travel, promises further improvements. Future nodes will listen to ambient conditions and adjust communication frequencies accordingly, says Grant Deane of the Scripps Institution of Oceanography in La Jolla, California.

Another promising avenue is the use of laser pulses to beam information between nodes. Lasers require less battery power than acoustic signals and are far more discreet. Information is sent using cone-shaped beams to ensure that the signals reach light-sensing photodiodes on the receiving node, even when both nodes are moving. But this approach will work only over distances of a few tens of metres at best, according to a German military scientist working on the technology.

American researchers are developing fibre-optic UUV tethers dozens of kilometres long, which would allow high data rates. But long tethers can get tangled or cut by crabs. UUVs will probably play a bigger role as roving wireless nodes that increase the reach of underwater networks. The latest “glider” UUVs consume very little battery power: rather than turn a propeller, batteries pump oil in and out of an external bladder, changing the UUV’s buoyancy. Fixed wings convert this rising and sinking into slow forward motion, allowing a glider to run for months on a single battery charge. Already, gliders serving as “mules” are descending to sensors in deep water where they acoustically collect information. They then ascend to the surface and send the data via radio, says David Kelly, chief executive of Bluefin Robotics, which provides UUVs to half a dozen navies.

The US Navy has ordered several gliders to form underwater mobile networks. With no engine noise, a stealthy “swarm” of gliders could monitor submarines and ships entering a strait, for example, surfacing to transmit their findings. Floating gateway nodes, dropped from the air, allow messages to be sent to submerged devices via low-frequency acoustic signals. This scheme, known as Deep Siren and developed by Raytheon, an American defence contractor, has been tested by the British and American navies.

Disconnected no more

“Underwater networking will put an end to the ‘data starvation’ experienced by submarines”

The combination of acoustic signalling and UUVs, which can deliver data physically, will put an end to the “data starvation” experienced by submarines, as America’s submarine command described it in a report last year. Often incommunicado, subs have been condemned to “lone wolf” roles, says Xavier Itard, head of submarine products at DCNS, a French shipbuilder. His firm is developing a funnel-shaped torpedo-tube opening that would make it easier for a UUV to dock with a submarine. Being able to send messages quickly via acoustic networks would enable submarines to take on more tactical roles—inserting special forces when needed to a nearby battlefield, say, or supporting ground operations by launching cruise missiles from the depths.

The Soviet-built ELF radio system remains a “backbone” of Russia’s submarine communications, according to a Norwegian expert. But in a clear vote of confidence in newer technologies, America shut down its own system in 2004. Thanks to steady progress in undersea networks, what was once a technological marvel was, a US Navy statement explained, “no longer necessary”. Whether via sound waves, laser pulses, optical fibres or undersea drones, there are now better ways to deliver data underwater.

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