Underwater sensor networks (UWSNs) are multipurpose grids of autonomous acoustic transmitter-receiver nodes with interdisciplinary applications ranging from bathymetry, hydrographic surveys, disaster prevention, to tactical surveillance. Acoustic transmission is the only viable option as of now as radio waves suffer from severe attenuation and optical transmission suffers severe scattering.

Due to the restrictive nature of seawater, harsh constraints are imposed on the network elements in terms of effective ranges, energy efficiency, and reliability. As acoustic waves are essentially pressure waves that traverse transversally across the medium, they mainly undergo losses due to spherical spreading and attenuation due to medium characteristics and transmission frequency. Unlike terrestrial networks, stability in location cannot be guaranteed and geolocation is restricted to inertial positioning based on externally predefined references.

As these nodes are incapable of independent or deliberate lateral movement, they must be deployed in a spatial arrangement that serves their intended purpose optimally, while being stable against disruption by drifting due to undercurrents. Most of them are effectively isolated from the outer world once deployed, and contingency procedures are required for alternate communication paths in case the primary route is compromised.

The transmission range (*R*) of acoustic waves in seawater depend on a variety of factors. Loss in transmission intensity due to spherical spreading is inversely proportional to the square of the distance traveled by the wavefront in a particular direction from the point source.

Attenuation in underwater acoustic propagation is influenced by several factors. The ones that are of utmost importance are temperature (*T*), salinity (*S*), depth (*z*), pH (*pH*), and transmission frequency (*f*). According to the currently accepted model of Francois-Garrison, the viscosity of pure water and the molecular relaxation processes of magnesium sulphate and boric acid cause varying degrees of losses in intensity can be expressed as the absorption coefficient (a) as follows:

As *T*, *S*, *z*, and *pH* tend to vary over a given region of interest, a – and by extension the attenuation – also varies. This non-linear variation needs to be accounted for with suitable granularity in a dynamic simulation to preconfigure a stable physical network layout of nodes.

Underwater sensors are designed to withstand the harsh, isolated environment of the deep seas to perform reliably over the longest possible time period without repairs, servicing, or recharging. As such, they are relatively expensive to acquire and deploy per unit. In the interest of maximizing potential gains from the available resources, for the general problem of maximizing coverage in three dimensions for a fixed number and specification of sensors, a dynamic network simulation is required in addition to deriving an optimal arrangement by modeling all vital characteristics.

The modeling of an optimal solution with reproducible accuracy in real life situations requires the following minimal set of data as input:

* Of sensors:
  1. Transmission frequency (*f*)
  2. Source level intensity (*SL*)
  3. Detection threshold intensity (*DT*)
* Of seawater:
  1. Temperature (*T*)
  2. Salinity (*S*)
  3. Depth (*z*)
  4. pH (*pH*)

For identical sensors or for echo-based detection scenarios, the difference between *SL* and *DT* may be thought of as the maximum acceptable loss in intensity (*TL*).

In deriving an optimal spatial arrangement of nodes for this scenario, an intelligent strategy needs to be implemented to maximize the total volume enclosed, while eliminating or at least minimizing shadow zones. We choose a genetic algorithm-based approach to solving this problem. Genetic algorithms provide an evolutionary approach towards solving such problems by aiming to improve the fitness of each successive generation, mimicking the natural selection on a suitably simplistic scale. An initial population of individuals is required, and is often randomly seeded. A fitness function is defined, which assigns a score to every member of the current population based on the evaluation of relevant characteristics. The fittest individuals from this pool are selected for creating the next generation. Additional factors like random mutation in genomes are also specified to reduce the chances of the solution converging towards a local maximum. Since shadow zones in such a scenario are essentially holes in the coverage shell, penalties are required to discourage such arrangements from participating in the evolution of the genome. In every successive generation, the score of the best-fit individual is expected to improve due to selective breeding. As the score stagnates with respect to average change in fitness, generation, or time, the algorithm terminates with the optimal solution as its output.

In our deployment strategy, we model a given set of sensor nodes as point sources with specified characteristics, and allow them to spread the spatial arrangement using a genetic algorithm. We create the initial population by randomly scattering the nodes in three dimensions such that every node is initially within range of every other node. In a real life situation, given the upper and lower depth bounds, the goal would be to secure the disk-like chunk in the slab of the water body. With each successive generation, the node arrangement is allowed to expand within these bounds. For every individual, a convex hull is stretched over the point cloud formed by the nodes in three dimensional space to form a polyhedron. The volume of this polyhedron not only serves as the initial score for the individual prior to constraint checking, but its visualization can also be used to identify shadow zones as well as highlight nodes surplus to requirements in achieving the given objective. Shadow zones can be born of holes in the facets of the polyhedron, or gaps in the edge coverage, which are a lot worse. To eliminate these gaps, every edge of every facet of the polyhedron is tested for overlap-accounted total edge coverage. As soon as the first violation of this constraint is found, the individual is rejected outright with a score of zero. Surplus nodes lie inside the polyhedron, and at best contribute to face coverage and alternate communication routes. A suitable fraction of the score is attributed to every node lying on the convex hull, and is used as the unit penalty score for every node that violates the specified bounds. In using this approach, nodes that lie within the convex hull, and thus do not contribute to the score of the individual, increase the unit bounds violation penalty, discouraging such arrangements as a side effect. In the case of the ultimate best-fit individual, a cost-benefit analysis of the solution might serve to decide the involvement of these nodes in the actual deployment.

The ranges of sensor nodes vary anisotropically with respect to the aforementioned medium characteristics. To ensure total coverage in the face of disruptive influences like undercurrents over time, a minimum overlap factor (*OL*) may also be defined as an additional constraint, which has the added benefit of redundancy in detection. There are two cases for determining the range of a point source in a particular direction:

1. Node communication:
   1. Two-way communication between a pair of nodes requires each node to be in the other's one-way transmission range in the respective directions:
2. Echo-based detection:
   1. Echo-based detection requires taking into consideration the two-way transmission losses in a particular direction and back:

Achieving echo-based detection while maintaining total edge coverage accounted for overlap satisfies communication ranges between the involved pair of nodes. For this, the edge length (*e*) must fit both ranges with the specified overlap:

For a given edge, ranges are determined by calculating a at intermediate points over its length and integrating the attenuation piecewise with a suitable granularity from both ends. As the two-way transmission losses approach *TL*, the echo-based detection range for each node approaches its maximum value in the direction of the other.