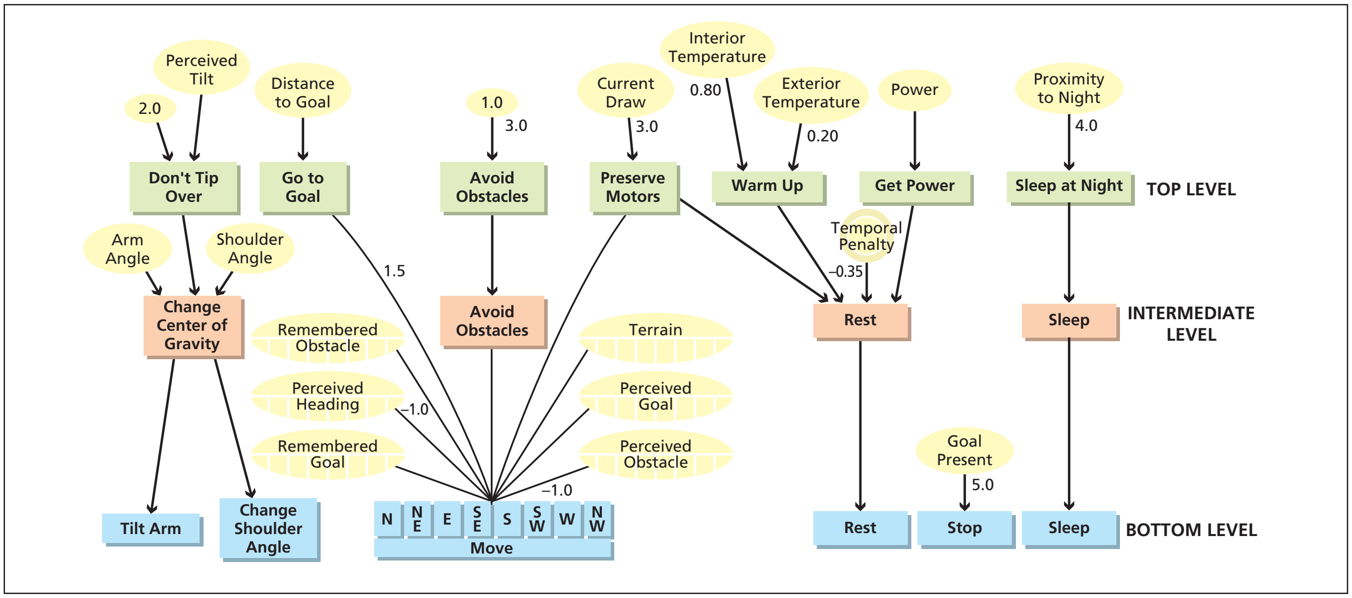


The **Free-Flow Action-Selection Hierarchy** includes multiple behaviors at different levels. The numerical values shown at several places are examples of weights assigned to inputs of behavioral modes. In general, such weights are changed as needed to adapt to changing or previously unknown environmental conditions.

Inputs to the behavioral nodes are calculated as weighted sums. In BISMARC, the weights are fixed; consequently, BISMARC is not capable of adaptation to changing conditions or to environments outside an original world model. In contrast, SMART includes a learning mechanism that adapts the weights to changing and previously unanticipated conditions: An algorithm, known in the art as the maximize collective happiness (MCH) algorithm, adjusts the weights in such a manner as to maintain the health of the robot while ensuring progress toward the goal.

This work was done by Terrance Huntsberger of Caltech for NASA's Jet Propulsion Laboratory.

The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-40899.

Protocol for Communication Networking for Formation Flying

This protocol provides for adaptation to changing formation geometry and communication requirements.

NASA's Jet Propulsion Laboratory, Pasadena, California

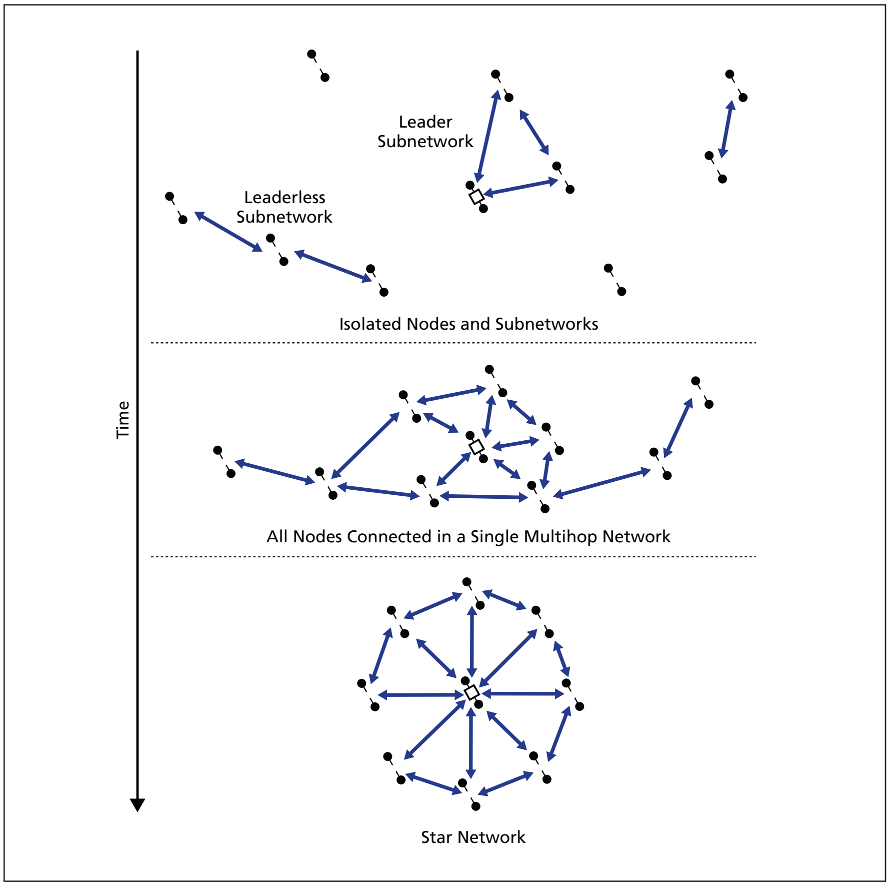
An application-layer protocol and a network architecture have been proposed for data communications among multiple autonomous spacecraft that are required to fly in a precise formation in order to perform scientific observations. The protocol could also be applied to other autonomous vehicles operating in formation, including robotic aircraft, robotic land vehicles, and robotic underwater vehicles.

A group of spacecraft or other vehicles to which the protocol applies could be characterized as a precision-formation-flying (PFF) network, and each vehicle could be characterized as a node in the PFF network. In order to support precise formation flying, it would be necessary to establish a corresponding communication network, through which the vehicles could exchange position and orientation data and formation-control commands. The communication network must enable communication during early phases of a mission, when little positional knowledge is available. Particularly during early mission phases, the distances among vehicles may be so large that communication could be achieved only by relaying across multiple links. The large distances and need for omnidirectional coverage would limit communication links to operation at low bandwidth during these mission phases. Once the vehicles were in formation and distances were shorter, the communication network would be required to provide high-bandwidth, low-jitter service to support tight formation-control loops.

The proposed protocol and architecture, intended to satisfy the aforementioned and other requirements, are based on a standard layered-reference-model concept. The proposed application protocol would be used in conjunction with conventional network, data-link, and physical-layer protocols. The proposed protocol includes the ubiquitous Institute of Electrical and Electronics Engineers (IEEE) 802.11 medium access control (MAC) protocol to be used in the data-link layer. In addition to its widespread and proven use in diverse local-area networks, this protocol offers both (1) a random-access mode needed for the early PFF deployment phase and (2) a time-bounded-services mode needed during PFF-maintenance operations. Switching between these two modes could be controlled by upper-layer entities using standard link-management mechanisms.

Because the early deployment phase of a PFF mission can be expected to involve multihop relaying to achieve network connectivity (see figure), the proposed protocol includes the open shortest path first (OSPF) network protocol that is commonly used in the Internet. Each spacecraft in a PFF network would be in one of seven distinct states as the mission evolved from initial deployment, through coarse formation, and into precise formation. Reconfiguration of the formation to perform different scientific observations would also cause state changes among the network nodes. The application protocol provides for recognition and tracking of the seven states for each node and for protocol changes under specified conditions to adapt the network and satisfy communication requirements associated with the current PFF mission phase. Except during early deployment, when peer-to-peer random-access discovery methods would be used, the application protocol provides for operation in a centralized manner.

The central communication node, denoted the "leader" spacecraft, would be selected so that its position in the formation tended to be spatially in the center. For example, PFF interferometry missions are typically configured with a single "combiner" that is centrally located relative to the other spacecraft. Selection of the spatially central node as the central communication node would leverage the special characteristics of the PFF networking problem domain in order to achieve high communication efficiency. In particular, when the spacecraft had positioned themselves into coarse formation, the IEEE 802.11 MAC protocol could be adapted from "distributed coordination function" (DCF) mode (a peer-to-peer random-access mode) to "point coordination function" (PCF) mode, in which the leader would act as the "point coordinator", so that time-bounded services needed to support time-critical control could be activated.



A **Communication Network** would evolve as spatially dispersed nodes moved into a coarse formation and then into a tightly controlled precise formation. The proposed protocol would enable communication among the nodes at all phases of evolution of the network.

Furthermore, if antenna patterns were biased to afford higher gain when the spacecraft were in coarse formation, the protocol could recognize these conditions and cause higher data rates to be used in communications. It should be noted that in conventional applications of the IEEE 802.11 MAC protocol in "ad hoc" networks, such *a priori* knowledge of antenna gain patterns and other features of network spatial configurations cannot be assumed and utilized. The predictability of the spacecraft formation would make it possible to utilize them in the proposed protocol.

This work was done by Esther Jennings, Clayton Okino, Jay Gao, and Loren Clare of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.
NPO-41486

Planning Complex Sequences Using Compressed Representations

Computation time and memory needed to generate schedules are greatly reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method that notably includes the use of compressed representations interleaved with non-compressed (time-line) representations of a general scheduling problem has been conceived as a means of increasing, by orders of magnitude, the speeds of computations needed for scheduling complex sequences of activities that include cycles wherein subsets of the activities and/or sequences are repeated. The method was originally intended to be used in scheduling large campaigns of scientific observations by instruments aboard a spacecraft. A typical such campaign could include observations of millions of targets, many observations to be made during long repeated passes. The method would also be useful on Earth for scheduling complex sequences of activities that include cycles.

The method is best summarized in the context of the original intended application, wherein the scheduling problem is formulated as that of selecting, from a candidate set of observations, those observations that cover as many target points as possible without oversubscrib-