Agile Information Control Environment Program

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Efficient and precise management and control of information flow are key components in winning information warfare. We discuss two new APL Agile Information Control Environment Program projects for the Defense Advanced Research Projects Agency. These two projects will develop a theoretical foundation and enabling technology to dynamically manage and control information flow across a distributed and heterogeneous network infrastructure comprising military and commercial networks. (Keywords: Adaptive information control, Discrete event systems, Dynamic channel building, Global QoS optimization, Tactical networks.)

INTRODUCTION

The goal of the Agile Information Control Environment (AICE) Program, established by the Defense Advanced Research Projects Agency (DARPA), is to develop a theoretical foundation and enabling technology to dynamically manage and control information flow across a distributed and heterogeneous network infrastructure. Future Joint warfare will require a huge amount of information sharing among several users over many dissimilar tactical and commercial networks. Depending on the associated applications or missions, different information flows might require different quality-of-service (QoS) guarantees from the networks that carry them. Some possible QoS factors are throughput, maximum delay, reliability, and covertness. Several DoD programs have been established to develop tactical network infrastructures to facilitate information sharing with heterogeneous QoS requirements among multiple sensory systems and military users, for example, the Cooperative Engagement Capability (CEC). Nevertheless, no mechanism currently exists that permits dynamic control and optimization of information flow over multiple tactical and commercial networks at a scale required by future Joint warfare. The ultimate objective of the AICE Program is to achieve information control in a faster, more efficient, and more precise way than our adversaries.

Four-Layer Functional Architecture

DARPA envisions a four-layer functional architecture for AICE, as shown in Fig. 1.

- Physical network: This layer will consist of many independently owned and operated tactical and commercial networks that in general provide routing services and unique QoS capabilities. These are the actual communications resources on which the information flows will travel.
- MetaNet: Future military information operations will use a variety of commercial and DoD communications systems and networks. Information will be

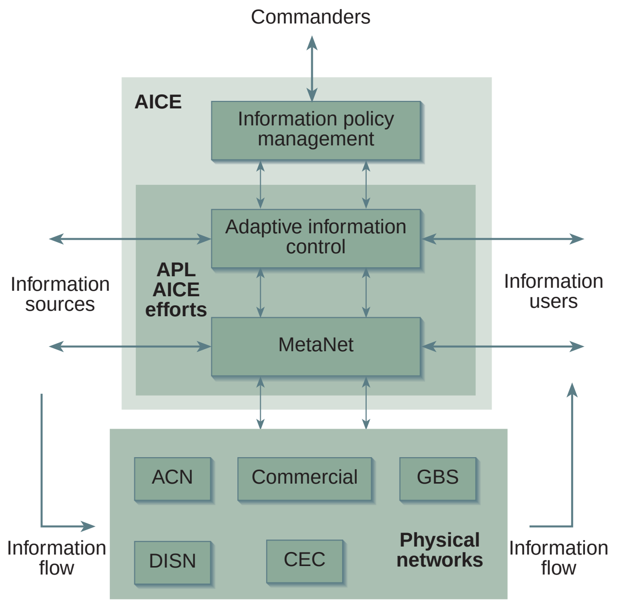

Figure 1. DARPA AICE functional architecture. (ACN = Airborne Communication Node, DISN = Defense Information System Network, CEC = Cooperative Engagement Capability, GBS = Global Broadcast Service.)

disseminated based on the QoS required by the user, and the requisite networks will be selected on a per-message basis for their ability to achieve QoS. The MetaNet system facilitates QoS-based routing over this collection of networks. MetaNet has four aspects: (1) inserting QoS-like capabilities into existing tactical networks to enable dynamic reallocation of network resources, (2) negotiating service requests as an intermediary between the user and individual networks, (3) providing end-to-end QoS solutions within time constraints, and (4) maintaining negotiated end-to-end QoS by dynamically re-routing or renegotiating service.

- Adaptive information control (AIC): This layer provides global "content-aware" dynamic information flow control, using the services of the MetaNet layer to do so. Features of the AIC layer include partitioning of information flows among available logical channels, globally optimizing allocation to achieve information flow priorities for military users, developing profiles of user information dissemination needs, reallocating resources when necessary owing to network QoS degradation, and managing flow control to accommodate real-time communications.
- Information policy management (IPM): This layer has three primary functions: (1) it provides users the capability to visualize the effects of their information control policies, (2) it relates information policy management to military operations, and (3) it aids in the synthesis of effective information control policies.

The DARPA AICE Program focuses on MetaNet, AIC, and IPM. APL's AICE efforts will include two 3-year projects beginning in January 1999 (the second and third years are optional) focused on the MetaNet and AIC layers. These two projects are collaborative efforts involving APL, Purdue University, and the University of Missouri-Columbia.

APL METANET PROJECT

The goal of the MetaNet Project is to develop an intelligent MetaNet controller (IMC). The main tasks of the MetaNet layer are to negotiate and coordinate the setup of end-to-end QoS across multiple, dissimilar QoS networks and to perform internetwork routing. It will provide a set of end-to-end logical channels (each logical channel normally runs across several physical networks) with specific guaranteed QoS to the AIC layer for information flow control. It will also monitor the network traffic status of each established logical channel and report any change in channel QoS to the AIC layer for appropriate responses or necessary information channel reconfigurations.

APL will develop an IMC as a component of the AICE Program. A key feature of our design is the treatment of the process of delivery of QoS to communications system users in a control-theoretic manner using supervisory control. The core controller will be synthesized as a Discrete Event System (DES) model and supplemented by artificial intelligence and heuristic techniques. Unanticipated events will be handled as perturbations to achieve a control state defined by the QoS goal. The output of the controller will consist of actions necessary to overcome the perturbations.

The IMC will serve as an interface to four military tactical communications systems: (1) the Mobile Subscriber Equipment and its Warfighter Information Network-Terrestrial (WIN-T) follow-on; (2) the Joint Composite Tracking Network, which is a follow-on to CEC and its Data Distribution System (DDS) communications component; (3) the Milstar Extremely High Frequency and Advanced Extremely High Frequency military satellite communications (Milsatcom) system; and (4) the Airborne Communications Node System. Access to these systems will be controlled according to the required QoS in a manner transparent to the user. The IMC concept will allow more efficient use of available networks for tactical communications applications than is currently achieved by eliminating the use of stovepipes in which information is always sent via a fixed medium.

The concept of operations for the IMC includes interfaces to a higher AIC layer and subordinate tactical communications networks. The AIC will pass to the IMC user requests for communications access along with a set of QoS requirements. The IMC will assess the available connectivity and QoS through negotiation with, and analysis of, the subordinate system's performance and capacity. Resulting solutions will be passed to the AIC, where connectivity decisions are made. The AIC will then inform the IMC, and the IMC will direct resource allocation in the chosen communications system to establish connectivity.

Military communications pose unique control challenges because of widely varying traffic priorities, rapidly changing environmental conditions, mobile networked field terminals, and enemy interference. Current control technology uses very simple and often *ad hoc* algorithms to react to these conditions and fails to exploit the richness of available software capabilities.

The IMC will build on concepts previously developed by APL for an intelligent controller for Milsatcom terminals as part of the DARPA Program for IMPACT (insertion into Milsatcom products advanced communications technology). Sophisticated models of network behavior can enable much-needed effective automated diagnosis and treatment of network QoS failures. Available capacity cannot be exploited without using adaptive congestion management algorithms that monitor and react to changing traffic patterns. Recent artificial intelligence research[1,2] in the area of reinforcement learning has made possible the design of adaptive scheduling and routing algorithms that react to traffic patterns, enabling more efficient use of bandwidth. Recent work[3,4] in supervisory control theory provides an additional perspective, allowing the use of adaptive tuning of parameterized network configurations to maintain QoS. A mathematical model of the network configuration management functions used in the IMC will be created and evaluated for speed and accuracy in assessing QoS, first with models of the subordinate communications systems and second in interface trials with those systems (see Fig. 2).

APL AIC PROJECT

The goal of the AIC Project is to develop novel AIC techniques for the AICE Program. The AIC layer will provide global content-aware dynamic information flow control using the content-unaware services of MetaNet. It must take into account the value of the information flow to the commander and optimize the use of overall QoS resources furnished by MetaNet. Our approach is built on a set of basic functional components, each performing a crucial subtask required by the AIC. To respond to a rapidly changing dynamic environment and to meet real-time performance constraints, the AIC layer constantly iterates over subtasks to accomplish the overall information control objective. Figure 3 shows the four functional components (AIC subtasks) of the APL approach:

1. Information flow aggregation. To enable effective logical channel negotiation with MetaNet and quick reconfiguration in response to various changes, the AIC layer first organizes the large set of information flows into a collection of smaller and more manageable groups by appropriate aggregation.
2. Logical channel negotiation with MetaNet. For each group of information flow in the established structure, the AIC layer negotiates with the MetaNet to establish one or more end-to-end logical channels to satisfy its total QoS requirements.

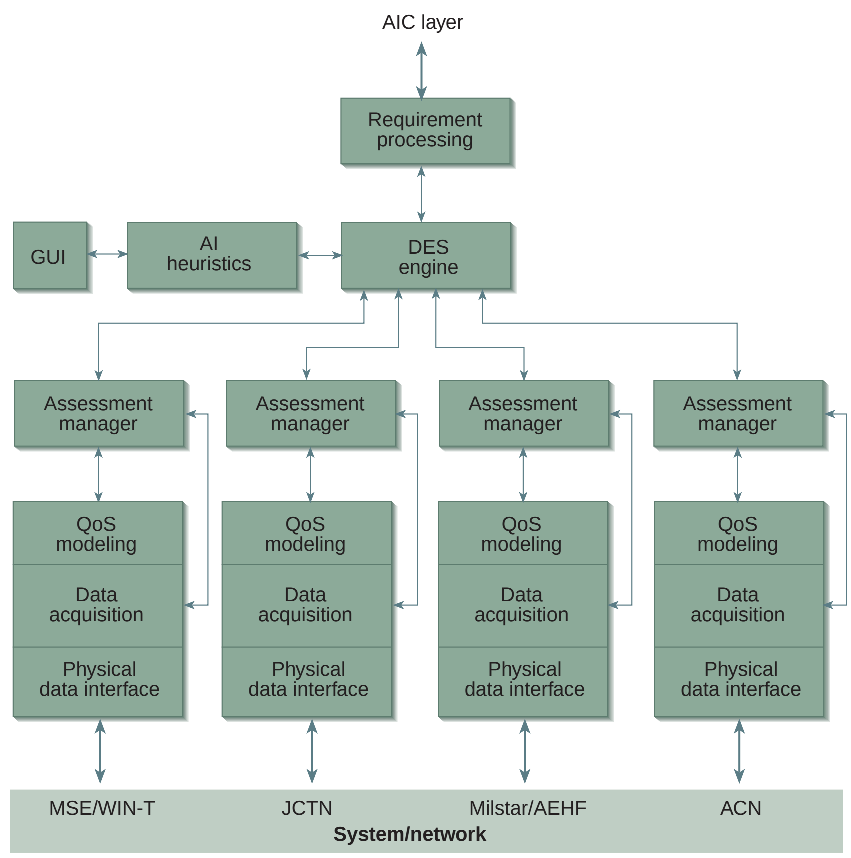

Figure 2. Intelligent MetaNet controller and interfaces. (AIC = adaptive information control, GUI = graphical user interface, AI = artificial intelligence, DES = Discrete Event System, MSE = Mobile Subscriber Equipment, WIN-T = Warfighter Information Network-Terrestrial, JCTN = Joint Composite Tracking Network, AEHF = Advanced Extremely High Frequency, ACN = Airborne Communication Node.)

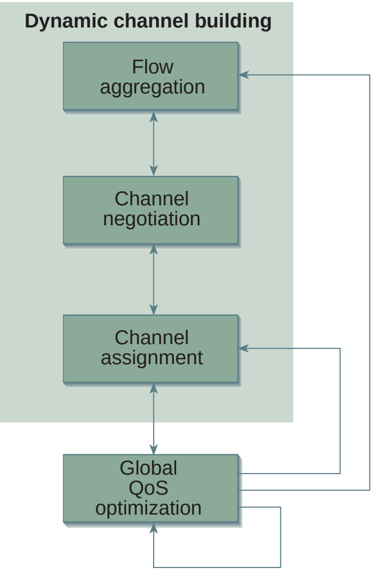

Figure 3. Functional components of AIC.

3. Channel assignment to information flows. Based on the set of end-to-end logical channels from MetaNet, which may not be exactly what was originally requested, the AIC layer assigns to each information flow a logical channel that meets the QoS requirements. In general, more than one information flow is assigned to each logical channel.
4. Global QoS optimization to allocate channel QoS resources. When traffic congestion occurs as a result of either channel degradation or over-subscription during the channel building stage, the AIC will optimize the allocation of overall channel QoS resources among information flows in accordance with commanders' operational priorities.

In a dynamic environment where the required information flows, network status, and commanders' priorities can all change with time, the AIC layer will need to iterate over the described subtasks with various scales in different orders. To react to rapid changes in information control requirements, APL will develop a scalable incremental reconfiguration scheme that properly coordinates the implementation of the four subtasks. Eventually, changes may cause the AIC to recalculate (in the background) a new set of proposed logical channels (i.e., subtasks 1 to 3 are repeated). At the conceptual or abstract level, the AIC layer faces a large-scale dynamic resource allocation problem (dealing with 10,000 users and 1,000 sources simultaneously, as estimated by DARPA). The size of the problem, the real-time constraints, and the variety of performance criteria will easily render any exact optimal solution impractical. We will develop efficient approximate algorithms that achieve near-optimal performance.

To better understand the issues and trade-offs presented by the large-scale adaptive information control problems faced by the AIC layer, we will also develop a mathematical framework that models the relevant factors and desired optimization criteria. This framework will serve as a scientific basis for our development of efficient AIC techniques for the AICE Program. Moreover, the framework will provide a rigorous way to assess the performance of techniques developed throughout the project. Finally, we will develop a working prototype for the AIC layer and demonstrate its performance by simulating information flow control in a large-scale military operation.

CONCLUSION

With APL's extensive experience in tactical network management and control, as well as expertise in large-scale computations and optimization, we believe that the two AICE projects presented in this article will lead to innovative and exciting technologies for the efficient dynamic information control of future large-scale Joint warfare.

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