Context Based Shared Understanding for Situation Awareness

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ABSTRACT

Situation Awareness requires teammates to share data with limited network bandwidth and computing power. These limitations require an intelligent method of selecting data for dissemination. Lockheed Martin Advanced Technology Laboratories (LM ATL) has created a selection process to track data and has extended this process for sending inferred and other relevant data, including semantic relationships, threat aggregates and enemy courses of action (ECOAs). With a wide variety of data to choose from, the selection process requires a rich set of criteria based on the needs of the teammates. These needs are captured in the context of each teammate. Context is made up of a role, current state, capabilities, and explicit or implied needs. The context is used to select data for dissemination in a threefold process: filtering, prioritizing, and sending the data. This paper will describe the evolution of the Shared Understanding technology developed at LM ATL.

1. Introduction to the Problem

Networked military platforms need the right information by the right users at the right time. There has been significant work on this topic for sharing fused track data, primarily in environments where sharing tracks for targeting is necessary. Examples are Link-16, CEC, and TCN. However, the system's goal is for all of the data to be presented to all participants. When there are many types of data, ranging from tracks to ECOA to pictures, with different roles of users of the data, from analyst to commanders to reconnaisance team, there is information that is only relevant to certain participants. Generally, when passing data among peers, everything is shared, and when sharing with superiors, everything is shared. In addition, all of the data that is shared with subordinates often goes to all subordinates, not just the ones who need it. Figure 1 shows this typical hierarchical passing of messages. In this paradigm, messages are only passed across echelons (vertically). This approach of sharing everything with everyone results in high demand for communications bandwidth, which is a precious commodity in any operational battlefield environment. Since not every bit of available information is important to every recipient, some of that precious bandwidth will be spent for very little return in overall situation awareness value. In fact,

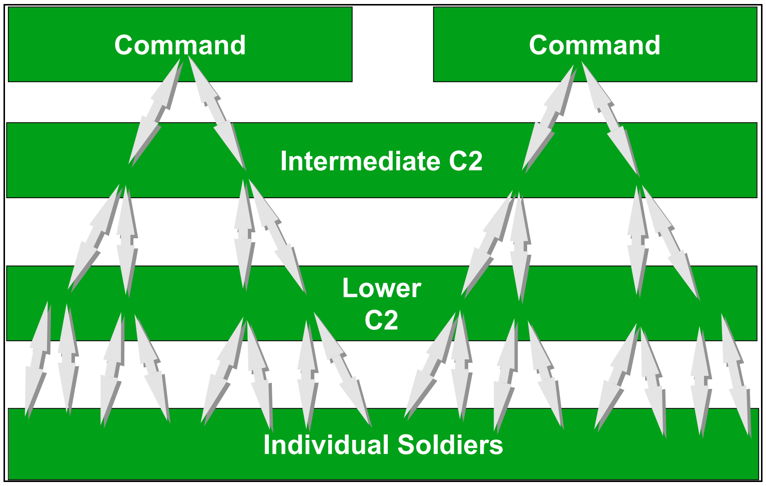

Figure 1. Current hierarchical information flow.

receiving information that is of no value to the recipient is a nuisance and distraction to the recipient, the return on the investment in bandwidth is negative.

To address this problem, LM ATL has developed an architecture for intelligent sharing of situation awareness data in bandwidth-constrained battlefield network environments. This patent-pending architecture, called “Grapevine,” is based on the idea that if you know or can infer the information needs of a recipient, you can make intelligent decisions about which bits of information provide the recipient with the most situation awareness value, in return for the cost of the bandwidth required to send it, and thereby obtain the maximum overall situation awareness benefit [1].

Figure 2 shows the Grapevine overlayed on the typical hierarchical message infrastructure. The Grapevine is shown with smaller arrows indicating the smaller amount of data being passed, since only relevant data is passed to each connected participant. In addition there are arrows that go across an echelon, indicating that peers can send and receive data to each other without a bottleneck at the commanding officer above them.

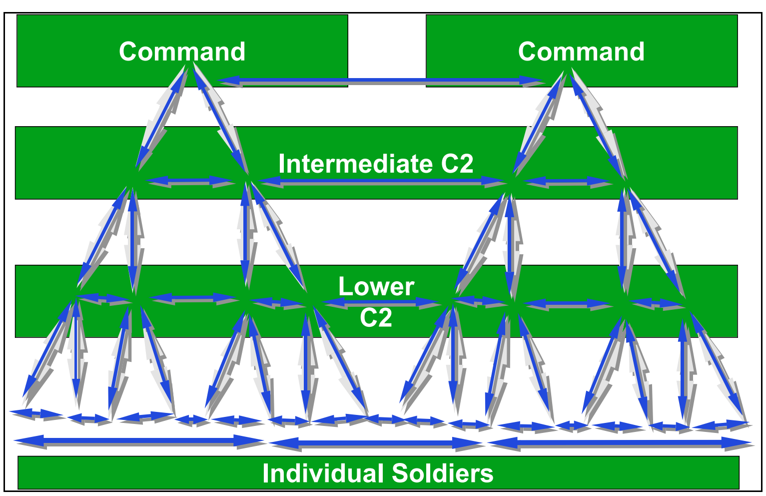

Figure 2. Grapevine's heterarchical information flow.

LM ATL began development of the Grapevine in 1997 for the DARPA Small Unit Operations program. The main purpose of the Grapevine in this case was to share relevant sensor data with a team of ground soldiers automatically, in order to provide a situation awareness display and alerting system. This work was transitioned to the Army's Dismounted Warrior C4I Science and Technology Objective program where the Grapevine technology was extended so that messages received by a peer could be sent to subordinates in a separate Grapevine. Later for the Army's Airborne Manned/Unmanned System Technology Demonstration (AMUST-D) Science and Technology Objective, and the Army's Hunter Standoff Killer Team Advanced Concept Technology Demonstration Programs, the Grapevine architecture was implemented to share sensor data between a Blackhawk helicopter, and a group of Apache helicopters over a low bandwidth radio. LM ATL has further transitioned the Grapevine architecture to the Office of the Secretary of Defense (OSD) Horizontal Fusion program within the Army's Warrior's Edge portfolio. This paper describes the lessons learned from historical versions of the Grapevine, our current implementation of Shared Understanding, and LM ATL's current research to improve this technology.

2. History

The Grapevine has evolved through a number of implementations. The basic structure of the Grapevine is that each node in the Grapevine has a proxy on every other node. The proxy has a process of filtering data, prioritizing data, and sending data. In past projects there were pieces that are now part of context, but there was no formal representation of operational context.

2.1 Small Unit Operations

The Grapevine in Small Unit Operations used LM ATL's Extensible Mobile Agent Architecture (EMAA) as our proxy and network layer over TCP/IP. Messages were translated as tracks and disseminated based on the decisions of software proxy agents in a point-to-point manner. Since there are different words that mean the same thing, such as human, which can also be called person, man, or woman, a set of aliases were created to disambiguate the data. In addition, reports were compared with an object type ontology so that additional data could be filled in if it were left out. This was based on an expert assessment of what fields go together based on the object type in the message. The aliasing and the ontology mapping of reports created enough information so that the proxy agent could intelligently decide what to send to its corresponding node. In this implementation new nodes can be discovered as long as they know the IP address of at least one other node in the system.

In Small Unit Operations, the filtering and prioritization methods used the same mechanism. Proxy agents sent messages to both peers, who were at the same echelon, and leaders who were one echelon above. The proxy agents filtered and prioritized for both sending a report and alerting on the report. Relevance was based on the potential danger of an entity identified by a sensor report to a teammate. A fuzzy rule engine computed the danger using proximity, estimated time of arrival, and combat power as criteria for the rules. Two separate thresholds were used to decide whether or not to send a report and whether or not to alert on the report.

2.2 Dismounted Warrior

For the Army's Dismounted Warrior C4I Science and Technology Objective program, LM ATL extended the Grapevine Technology to communicate to subordinates. In addition, a link was added so that data could be passed between two teams that were only connected via the radio of the leaders. A subordinate proxy agent was developed to enable a network where communication can travel to teammates at the same echelon but in different teams. A report was passed to the commander of one teammate, then to the commander of the other teammate, and finally down to the other teammate. For this to work properly, the commander's area of interest had to include the area of interests of the subordinates.

This was the first indication that the role of a teammate indirectly effects the data the teammate needs. In Small Unit Operations, there was a doctrinal concept that parents received everything that was of interest to the subordinate sending the report, and peers received what was in their area of interest, but there was no real need to have a different area of interest for members of higher echelons. However, in Dismounted Warrior, the area of interest for the Peer Proxy Agent had to change based on the location of the subordinates of that Peer. Without that dynamic change, the leader might not receive data that is pertinent to its subordinates.

2.3 Airborne Manned/Unmanned System Technology Demonstration (AMUST-D)

For AMUST-D, the filtering criteria were based on needs and capabilities. The criteria were shared between nodes, and sensor data was sent based on which types of data were needed the most. Filtering was based on a radius from the teammate and whether the sensor data was redundant to the teammate. The radius of interest differed based on the affiliation of the track. The radius values were pre-configured, but since they were based on the location of the teammate, the filtering area had to be updated as the teammate moved. Redundancy was checked based on the sensor reports that were sent by the teammate. If the sensor report is outside of the pertinent radius of interest, or a teammate has recently sent a similar sensor report, then the report is redundant and not sent. The proxy agent prioritized sensor reports based on specific classifications that were known to be dangerous to a helicopter.

For AMUST-D, on the Apache helicopter, data was disseminated from the situation awareness system through shared memory and sent over a low bandwidth radio with a human in the loop to its teammate Longbow Apache and Blackhawk helicopters. On the Blackhawk helicopter data is disseminated from the situation awareness system through a CORBA event channel interface to PCIDM middleware which sends data over a low bandwidth radio to the teammate Apache helicopters. This process is shown in Figure 3. In this system a commander was responsible for registration of data providers by adding them to a configuration file for each platform [2].

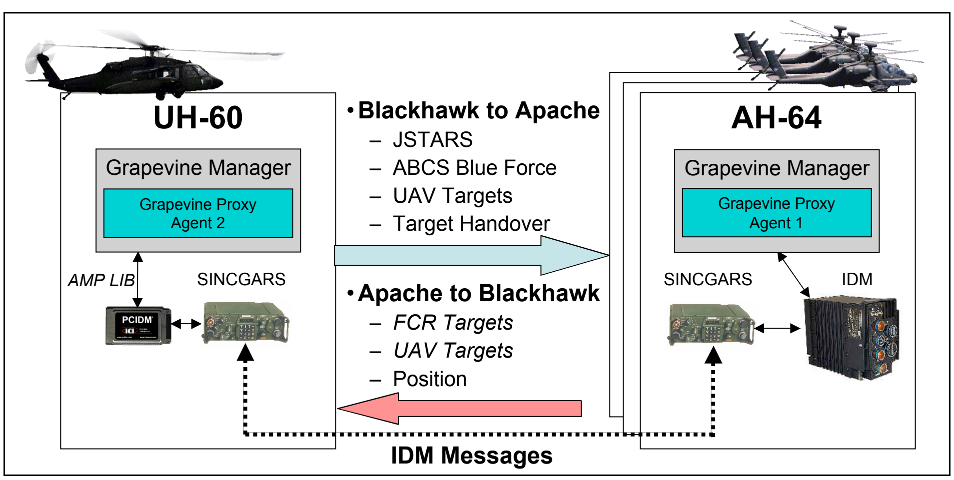

Figure 3. Grapevine implementation for AMUST-D, Targets with italics require a human in the loop.

For AMUST-D, the majority of the information that is needed to assess dissemination can be determined from a configuration that does not change. What does change in all of these cases is the location of the node. This location, though simple, is an integral part of the dissemination process. The location and the sensor data that a node has sent defines the "current state" part of the context structure.

3. Current Implementation of the Grapevine

The current Grapevine architecture consists of four sub-components as shown in Figure 4. Each of these sub-components operates asynchronously within the Grapevine Manager and supports a different aspect of intelligent information dissemination. The *Peer Awareness Manager* is responsible for maintaining the status of teammates within the networked Battle Space by exchanging operational context. The *Context Manager* is responsible for formulating the local operational context as well as processing remote teammate operational context to create or modify peer proxies. The *Peer Proxy Manager* maintains a set of peer proxies that applies information dissemination logic to the local data sources on behalf of each remote teammate. Finally, the *Communications Manager* transmits the information provided by the peer proxies, making optimal use of the communications resources on the local platform. LM ATL's current Grapevine architecture has been most recently applied to the Army's Warrior's Edge program, an initiative within the OSD's Horizontal Fusion program.

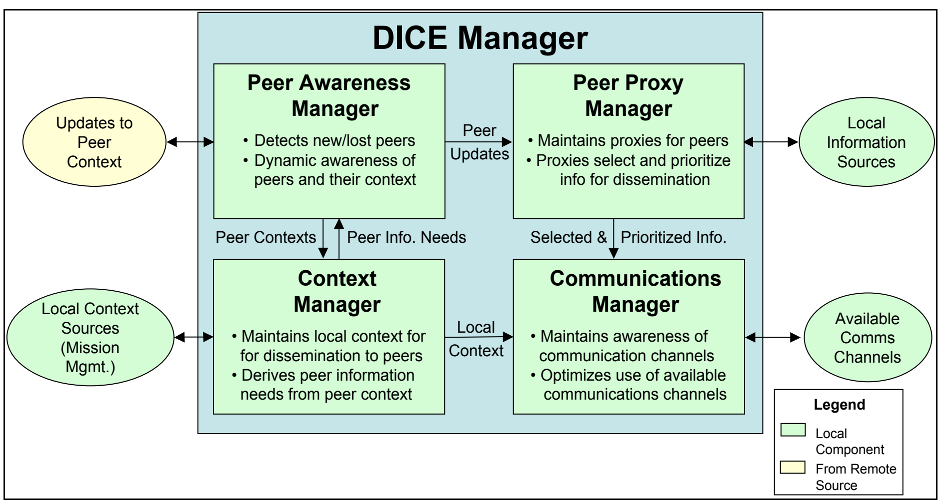

Figure 4. The Grapevine Architecture.

For Warrior's Edge, a service based approach was used for sharing data. In this approach, each Shared Understanding node registered itself with the Service Registry. The node checks the registry for other Shared Understanding services. For all services that it finds, it sends its context via a service method, and in turn other data providers share data to the node through a separate service method.

Each object is shared as an object associated with meta-data. The meta-data, which we call pedigree, stores source, validation, justification, security, and data type information. The pedigree structure is associated with a pedigree service. The pedigree service keeps track of pedigree for all data in the network. It also provides object initiation, object tracing, and object evaluation. The security portion of the meta-data is a placeholder so that a multi-domain system could be used with this architecture. The pedigree allows for flexible use of data structures. In addition, all objects in the system are part of an XML Schema, and this allows for easy translation and mediation of the data.

4. Current Efforts

With the architecture shown in Figure 4, LM ATL is enhancing Grapevine's intelligent information dissemination approach by employing a two-step process within the peer proxies. First, *Context-constrained Reasoning* uses peer operational context to decide which information is relevant to a teammate. This step can be thought of as dynamic information filtering process. Secondly, *Fuzzy Partial Prioritization* uses multiple attributes to assess the relative importance of information to a teammate. This step can be thought of as a sophisticated ranking process. Together these processes select and prioritize information for dissemination to each teammate.

4.1 Context-constrained Reasoning

Operational context encapsulates ideas of both mission and capabilities. More concretely, operational context contains information such as mission objective, role within mission, platform type, resource status, and surveillance capabilities. From the operational context, information needs of teammates are derived and Context-constrained reasoning is applied within the Proxy Manager to identify relevant information. The abstract rule-base used to construct a context-constrained reasoning engine is contained within the *Context Axiom Library* as shown in Figure 5. Based upon the specific operational context of a teammate, the Context Manager retrieves the applicable axiom templates, instantiates specific axioms and provides them to the Peer Proxy Manager (Figure 4) where Context-constrained Reasoning is applied to the local information sources for information selection.

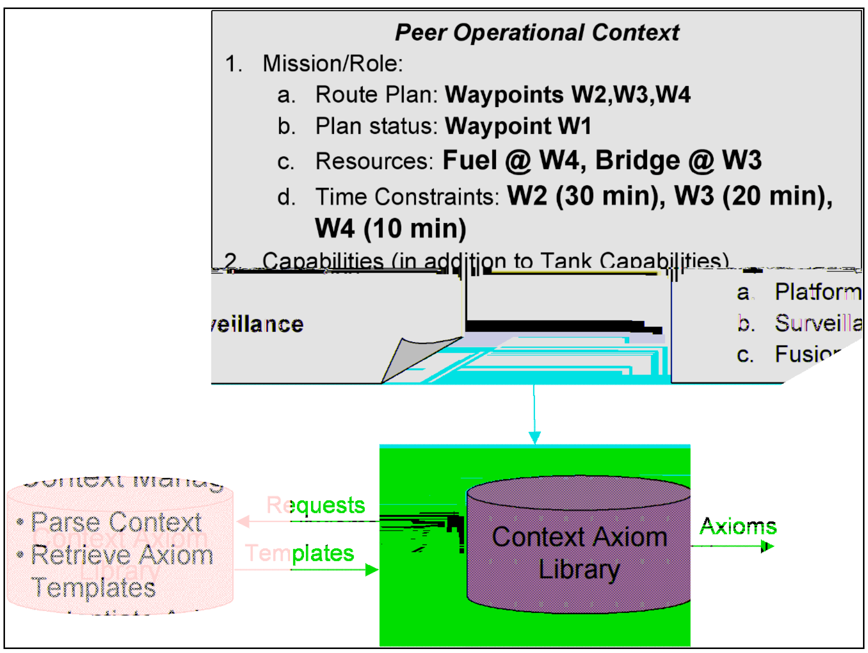

Figure 5. Dynamic development of axioms using remote operational context

4.2 Fuzzy Partial Prioritization

Context-constrained reasoning identifies relevant information, however, it is not sufficient, on its own, for providing an intelligent information dissemination capability. In addition to context-constrained reasoning, prioritization must be performed. LM ATL is developing a process called *Fuzzy Partial*

Prioritization that is based on the theory of fuzzy partial ordering. Contrary to Linear Prioritization, which assumes a pure ranking based on a strict relationship between attributes, Fuzzy Partial Ordering allows prioritization that considers propositional combinations of several attributes. As a simple example (Figure 6), consider prioritizing tracks based upon the attributes of speed and altitude. Linear Prioritization may yield the scheme illustrated on the left half of Figure 6. However, expressive and tactically significant prioritization schemes (such as those shown on the right half of Figure 6) cannot be applied using Linear Prioritization.

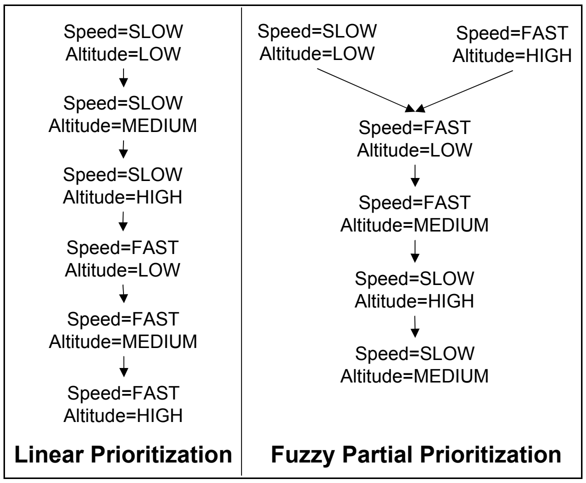

Figure 6. Fuzzy Partial Prioritization (right) is more expressive and tactically significant than Linear Prioritization (left) when multi-attribute prioritization is required.

5. Conclusion

This paper discusses the progress that LM ATL has made in data dissemination for track data and inferred data. The development of the Grapevine architecture has yielded a threefold solution to the intelligent dissemination of data. Filtering relies heavily on context to determine which data should be sent. Prioritization uses context to determine both time and mission criticality of data. Dissemination of data has been proven for many network and communications protocols.

References

[1] Stephen M. Jameson, "Architectures for Distributed Information Fusion To Support Situation Awareness on the Digital Battlefield," Fourth International Conference on Data Fusion, Montreal, Canada, August 7-10, 2001.

[2] Stephen Jameson and Craig Stoneking, "Army Aviation Situational Awareness through Intelligent Agent-Based Discovery, Propagation, and Fusion of Information," 2002.