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AN EVALUATION TECHNIQUE FOR A PROTOCOL IN DEVELOPMENT

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ABSTRACT

This paper presents a technique for evaluating a Local Area Network protocol in development. Existing protocol evaluation techniques such as simulation, complete implementation, and protocol verification are found to be inefficient in the evaluation of a protocol in development. A new protocol evaluation process is formulated to help quickly assess if the Xpress Transfer Protocol (XTP) meets the real-time data communications requirements of the Navy. The evaluation technique combines a detailed analysis of the XTP specification with attempts to implement selected parts of the protocol. Special attention is given to those aspects of the protocol that affect real-time tactical data communications.

The protocol evaluation process is found to be appropriate for evaluating XTP, concluding that a number of areas of the originally proposed protocol are not sufficiently specified or fail to meet the military needs of the Navy. Timely feedback to the protocol developers enables them to implement changes that solve the problems found. The conclusions of the evaluation are quickly produced because of the new protocol evaluation technique.

1. INTRODUCTION

Evaluating a protocol can be a difficult problem. This is especially true when evaluating a protocol in development. Standard evaluation techniques, such as simulation, may not be appropriate in this type of environment. Because simulations rely on the stability of the specification of the system being simulated, conventional validation techniques are not applicable; thus simulation is found to be unsuitable in this evaluation environment. A new protocol evaluation technique, adapted to this environment, is presented.

This effort is part of an ongoing project by the Information Transfer Architectures Group at the Naval Surface Warfare Center which began in late 1988. It includes work presented in [Irey 1989].

2. BACKGROUND

Traditionally, Naval Tactical Data Systems have performed real-time data communications using fast point-to-point connections. Today, Local Area Networks (LANs) are being used to achieve the connectivity needed to support the greater numbers of computers required to solve tactical problems.

LAN functionality is logically divided into seven layers in the ISO Reference Model [ISO 1984] as shown in Figure 1. The functions of the layers range from issues concerning the communication medium at the Physical layer (i.e. device interconnection properties) to software considerations for process to process communications at the Application layer. Of the seven layers in the ISO Reference Model, the Network and Transport layers are studied in detail in this research.

The Network layer performs operations concerned with routing information between transport entities within a network environment. Congestion control functions are also performed at this layer.

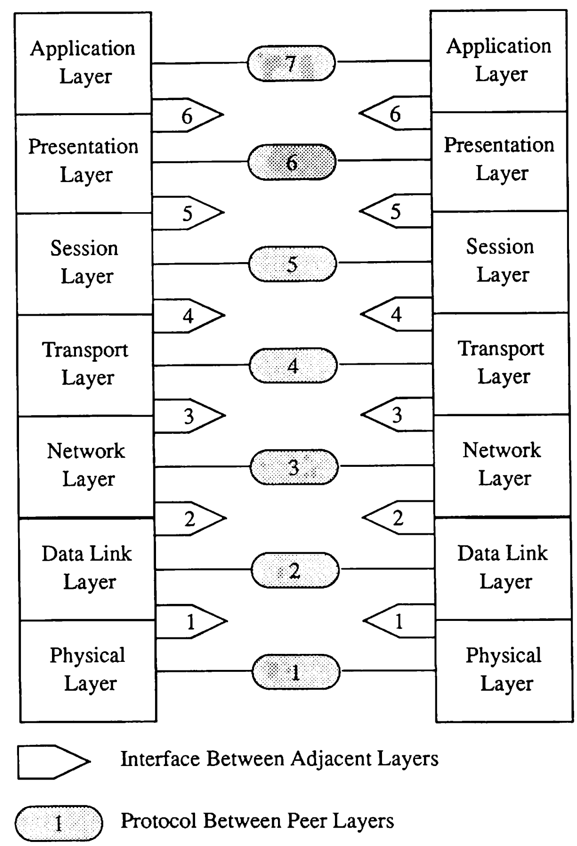

Figure 1. The ISO/OSI Reference Model

The main functions provided by the Transport layer include: the packetization and reassembly of messages, the detection and correction of errors which occur at the Network layer or below, and the multiplexing of transport connections onto network connections.

2.1 Addressing the Communications Requirements of the Navy

The Survivable Adaptable Fiber-optic Embedded NETwork (SAFENET) committee, formed by the United States Navy, is investigating LAN concepts applied to tactical systems. The committee is tasked with writing the SAFENET Military Standard [Green and Marlow 1989] which specifies needs and identifies extant protocols at all layers of the ISO Reference Model.

2.2 Existing Transport Protocols

The SAFENET committee determined that traditional transport protocols, such as TP-4 and TCP, can not meet the demanding communications requirements of the Navy. For example, target track positional data is best distributed using reliable multicast connections at the transport layer. Both TP-4 and TCP lack multicast capabilities. To meet real-time scheduling requirements, a priority scheme with a fine granularity is needed. Again, both TP-4 and TCP lack this mechanism. The committee evaluated a number of protocols in development and selected XTP for further detailed study as a candidate for the real-time transport protocol used in SAFENET.

2.3 The Xpress Transfer Protocol

XTP is a new protocol being developed in a joint venture by Silicon Graphics, Incorporated (SGI) and Protocol Engines, Incorporated (PEI). It provides both Network and Transport layer functionality. This combined layer architecture, referred to as a Transfer layer, is designed to provide much better performance than existing reliable transport protocols. By reducing the amount of control information which must be transmitted between nodes in order to ensure reliable data transfers, XTP may reduce the latencies inherent in current non-real-time protocols.

XTP is designed to provide complete Transfer layer functionality in Very Large Scale Integration (VLSI) circuits. The first silicon implementation of XTP is being realized in the joint Protocol Engine venture [Chesson 1987]. The Protocol Engine is designed to provide real-time communications at the 100 Mbit/second speeds required by Fiber Distributed Data Interface (FDDI) networks.

3. GOALS OF THE REAL-TIME TRANSPORT PROTOCOL EVALUATION

To support the SAFENET detailed study of the XTP protocol, an evaluation effort is taking place at NSWC. The goals of the evaluation are to ensure that the protocol meets the needs of the military and to quickly provide feedback to the protocol design team on where XTP fails to meet these needs.

Five steps are formulated to achieve these goals:

(1) verifying that a valid implementation can be built from the XTP Protocol Definition,
(2) showing that valid implementations can enable meaningful communication,
(3) demonstrating the exclusion of hardware dependencies from the protocol,
(4) showing that the protocol is robust, and
(5) determining whether XTP provides the performance needed for real-time Naval applications.

Results must be produced quickly in this study (i.e. within a few weeks of a protocol definition release) because of the unique evaluation environment. The Navy has found that the XTP protocol meets most of its needs, but does not meet all of them. In an effort to correct this, the Navy is providing feedback to the protocol design team for consideration in the next release of the protocol definition. While feedback presents the protocol designers with the concerns of the Navy directly, it has no impact on the protocol definition if it is not delivered to them on time.

3.1 Problems in Evaluating a Protocol in Development

In the early stages of development, a protocol definition can be constantly changing. The protocol developers may be experimenting with many different options. A standard reference can not be formulated since changes are occurring too rapidly. Both the standard reference and verification test suites would be undergoing constant updating. The size and complexity of typical verification test suites prohibits standardization.

Complete implementation can be used to achieve all of the steps of the evaluation. This is, as would be expected, the most expensive technique. It is even more expensive in the environment of a protocol in development since the engineering of the protocol implementation is concurrent with the actual protocol design. A design based on one revision of the protocol may be rendered inadequate by another revision of the protocol.

Protocol verification techniques can be used to complete the first and second steps of the study. These techniques rely on a standard reference (i.e. a protocol definition), against which all emulations of the reference are judged.

Simulation, partial and complete implementation represent viable approaches to protocol evaluation under less demanding time constraints. Combinations could also be employed to examine the behavior of a protocol at varying levels of detail. Steps 1 and 5 above are particularly amenable to simulation with a stable protocol definition.

Changing the model to reflect the current state of the protocol increases confidence in the simulation, but can also change the results. Interpreting the many sets of resultant data and continuously changing the model can be prohibitively expensive in the use of time and resources. Model validation is made virtually impossible because a reference system does not exist.

3.2 Reformulating the Goals of the Real-Time Transport Protocol Evaluation

Reexamination of the steps required to achieve the goals of protocol evaluation is necessary to cope with the limitations in evaluation techniques. Revision of the evaluation goals reduces the original five steps to three steps:

(1) verifying that a valid implementation can be built from the XTP Protocol Definition,
(2) showing that valid implementations can meaningfully communicate, and
(3) showing that no hardware dependencies exist in the protocol.

Elimination of steps 4 and 5 follows from the conclusion that simulation is prohibited because of the lack of a stable protocol definition. With the elimination of simulation, partial and complete implementation remain as the means for obtaining performance information. In reality, only partial implementation is viable, but the cost of obtaining only selected performance data is judged less important than the verification of an operable XTP definition.

While robustness is a primary requirement, assuming that interoperability exists is a precursor to evaluating it. Thus, robustness is not included in the revised goals.

4. A NEW PROTOCOL EVALUATION TECHNIQUE

A new approach for protocol evaluation is defined to achieve the goals of the XTP study. The approach uses two procedures: (1) a formal protocol definition review and (2) an implementation of selected parts of the protocol. Each procedure serves to mutually confirm the results of the other.

This technique is believed to be of value for any protocol in development. The approach defined is especially valuable in the incremental development of a protocol. This process is shown in Figure 2.

The detailed reviews provide feedback to the protocol designer, who uses the comments to clarify the Protocol Definition. The implementation procedure uncovers intricate problems in the

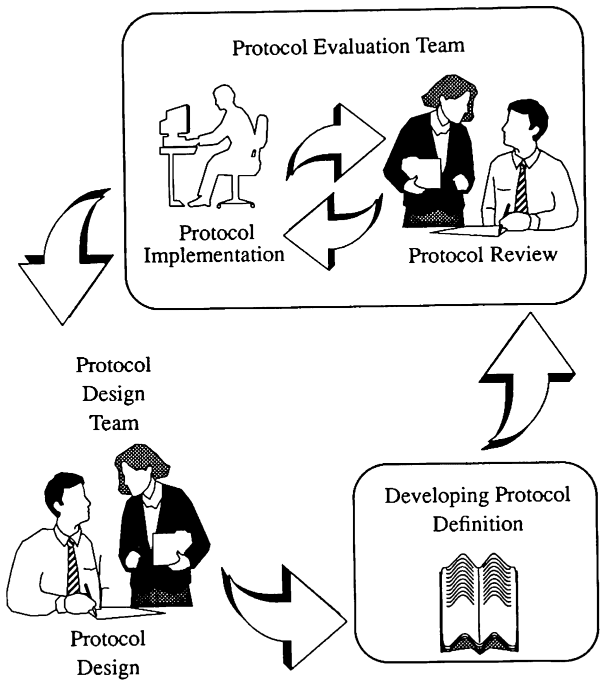

Figure 2. The Protocol Evaluation Process

Protocol Definition (typically related to inconsistencies among different parts of the protocol) not revealed in the detailed review procedure. These intricacies are highlighted for examination in a subsequent detailed review.

5. APPLYING THE PROTOCOL EVALUATION TECHNIQUE TO THE XPRESS TRANSFER PROTOCOL

The initial detailed reviews of XTP proved to be invaluable in the XTP study. Five major protocol elements are found to be either insufficiently specified or unsuitable for implementation in a tactical environment. A substantial amount of time is saved in the XTP implementation by the early recognition of unsuitable elements.

An implementation of the protocol subset selected is designed. The design process and realization of the design find a number of problems which are not uncovered in the detailed reviews. The revealed problems are only found because of the rigorous analysis mandated to implement the design.

6. RESULTS OF THE XTP EVALUATION

Applying the new protocol evaluation technique reveals several advantages over traditional approaches: faults in the protocol definition are quickly revealed, only selected parts of the protocol have to be implemented, and a concentrated effort can be made on the interactive behavior of the protocol. These advantages all directly contribute to achieving the goals of the XTP study.

The first advantage, faults in the protocol definition are quickly revealed, results from the detailed reviews. Instead of spending a lot of time planning a system design, as would be done in a complete implementation, or defining a model to be evaluated, as would be done in a simulation, the Protocol Definition is critically reviewed. Problems are found quickly due to the direct analysis of the Protocol Definitions.

The results of the protocol reviews have a direct impact on subsequent Protocol Definitions because they are promptly delivered to the protocol designers. This contributes to the goals of the XTP study because parts of the protocol found to be inadequate for military use are documented. This gives both potential military users and the protocol design team definite feedback on the applicability of XTP for use in tactical applications.

A large number of problems are pointed out in the detailed reviews of XTP and communicated to PEI. Their direct impact on the XTP Protocol is seen in subsequent releases of the Protocol Definition. For example, in a detailed review of the Revision 3.1 of the XTP Protocol Definition, it is shown that the extension field of a packet renders the packet unparsable. For a protocol to be considered for military use, specification problems such as this must be corrected in the Protocol Definition. Because the detailed review containing this comment is delivered to PEI before the next release of the Protocol Definition, the problem is corrected in the next revision of the document.

The second advantage, that only selected parts of the protocol have to be implemented, has a direct impact on the implementation effort. The only parts of the protocol implemented are those found worthy in the detailed reviews. Because of the reduced scope of implementation, a concentrated effort can be made in implementing the selected features. By spending a little time up front in the detailed reviews, less time is spent trying to implement protocol features which have specification problems. Again, time is saved and results are quickly delivered to PEI.

In a complete protocol implementation, all aspects of the protocol have to be built so the new evaluation process has an obvious advantage. Partial simulation can be done, however, but deciding what to simulate can be a problem. A detailed review of the Protocol Definition should be done to narrow the scope of the simulation.

The final advantage, a concentrated effort can be made on the interactive behavior of the protocol, is realized because of the time saved in the implementation effort. As pointed out above, only selected parts of the protocol are implemented. A level of confidence is achieved that these parts of the protocol have no "obvious" problems. Once these protocol elements are built, the interactions among them can be studied. Since questionable protocol elements are not even implemented, their interaction with other protocol elements is not studied allowing more time to be allocated to the worthy parts of the protocol.

7. LESSONS LEARNED

The synergy of combining the protocol evaluations with the implementation of selected parts of the protocol is found to be most appropriate in achieving the goals of the real-time transport protocol study.

Since problems which exist in the XTP Protocol Definition are uncovered early during the detailed protocol review procedure, they can be acted upon by the protocol design team and incorporated in the next revision of the protocol definition. The partial implementation serves to uncover more subtle and in-depth problems. A comparison can be made between results of the two procedures.

The detailed review procedure tends to find problems dealing with a single aspect of the protocol, e.g. problems in how the XTP checksum is calculated. This problem deals strictly with one aspect of the XTP protocol, stopping further consideration of the checksum algorithm. No analysis is done on how this algorithm might affect or be affected by other parts of the protocol.

The partial implementation procedure examines the highly complex interactions between parts of the XTP protocol, peer XTP subsystems, and XTP applications. Temporal relationships, which are beyond the scope of detailed reviews, are made visible in the second procedure. For example, problems with the initialization of XTP context records are found. The problems indicated only become apparent after several packets are exchanged between peer XTP subsystems.

Another problem missed during the detailed reviews deals with zero length messages. Military applications might use these to send keep-alive packets over a connection from an application process. The possibility of sending such a message is not considered during the first procedure because the realm of XTP application needs is inadequately understood until an actual application is designed ano tested. The needed analysis is difficult during this procedure because of the many complex interactions among parts of the protocol. Often these interactions only become visible in a working implementation. This is where the second procedure, partial implementation, proves to be a valuable technique in incrementally developing a protocol.

Detailed reviews and partial implementation employed separately yield useful information in evaluating a protocol in development. However, combining the two procedures produces a more substantive evaluation, allowing a more in-depth assessment, and making a more effective use of the time spent on the study.

While a simulation of XTP has not been performed to date as part of this research, such an analysis would provide useful information not provided by the detailed reviews and partial implementation. Each type of analysis has distinct advantages. Simulation can address performance issues in large systems (i.e. a network with 100 nodes) that are too costly to implement. Implementation may be able to find detailed problems which are perhaps overlooked in a simulation. This is due to the fact that an implementation deals with the protocol directly while simulations tend to deal with protocols in more abstract terms.

The new evaluation technique restricts the number of alternatives considered to those that are believed to be feasible. If used as a prelude to simulation, better results can be produced since simulations do better with the evaluation of higher level objects that follow the realization of a more constrained number of alternatives.

8. CONCLUSIONS

The protocol evaluation technique presented has a number of advantages over simulation, protocol verification, or complete implementation in evaluating protocols in development. These advantages include: faults in the protocol definition are quickly revealed, only selected parts of the protocol have to be implemented, expensive statistical analysis is avoided on elements that are discarded early, and a concentrated effort can be made on the interactive behavior of the protocol. The advantages allow a more in depth study to be done by making a more effective use of resources during the evaluation.

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