                         Executive Summary
                        of the NRC Report on
                       Transport Protocols for
                       Department of Defense
                           Data Networks

STATUS OF THIS MEMO

   This RFC is distributed for information only. This RFC does not
   establish any policy for the DARPA research community or the DDN
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INTRODUCTION

   This RFC reproduces the material from the "front pages" of the
   National Research Council report resulting from a study of the DOD
   Internet Protocol (IP) and Transmission Control Protocol (TCP) in
   comparison with the ISO Internet Protocol (ISO-IP) and Transport
   Protocol level 4 (TP-4). The point of this RFC is to make the text
   of the Executive Summary widely available in a timely way. The order
   of presentation has been altered, and the pagination changed.

   The title of the full report is:

                       Transport Protocols for
                       Department of Defense
                           Data Networks

                   Report to the Department of Defense
                   and the National Bureau of Standards

           Committee on Computer-Computer Communication Protocols

       Board on Telecommunications and Computer Applications Commission on
                   Engineering and Technical Systems
                     National Research Council

                       National Academy Press
                  Washington, D.C. February 1985

                                OVERVIEW

     The project that is the subject of this report was approved by the
     Governing Board on the National Research Council, whose members are
     drawn from the councils of the National Academy of Sciences, the
     National Academy of Engineering, and the Institute of Medicine. The
     members of the committee responsible for the report were chosen for
     their special competences and with regard for appropriate balance.

     This report has been reviewed by a group other than the authors,
     according to procedures approved by a Report Review Committee
     consisting of members of the National Academy of Sciences, the
     National Academy of Engineering, and the Institute of Medicine.

     The National Research Council was established by the National Academy
     of Sciences in 1916 to associate the broad community of science and
     technology with the Academy's purposes of furthering knowledge and of
     advising the federal government. The Council operates in accordance
     with general policies determined by the Academy under the authority
     of its congressional charter of 1863, which establishes the Academy
     as a private, nonprofit, self-governing membership corporation. The
     Council has become the principal operating agency of both the
     National Academy of Sciences and the National Academy of Engineering
     in the conduct of their services to the government, the public, and
     the scientific and engineering communities. It is administered
     jointly by both Academies and the Institute of Medicine. The
     National Academy of Engineering and the Institute of Medicine were
     established in 1964 and 1970, respectively, under the charter of the
     National Academy of Sciences.

     This is a report of work supported by Contract No. DCA-83-C-0051
     between the U.S. Defense Communications Agency and the National
     Academy of Sciences, underwritten jointly by the Department of
     Defense and the National Bureau of Standards.

     Copies of the full report are available from:

        Board on Telecommunications and Computer Applications Commission
        on Engineering and Technical Systems
        National Research Council
        2101 Constitution Avenue, N.W.
        Washington, D.C. 20418

                              PREFACE

     This is the final report of the National Research Council Committee
     on Computer-Computer Communication Protocols. The committee was
     established in May 1983 at the request of the Department of Defense
     (DOD) and the National Bureau of Standards (NBS), Department of
     Commerce, to develop recommendations and guidelines for resolving
     differences between the two agencies on a data communications
     transport protocol standard.

     Computer-based information and transaction-processing systems are
     basic tools in modern industry and government. Over the past several
     years there has been a growing demand to transfer and exchange
     digitized data in these systems quickly and accurately. This demand
     for data transfer and exchange has been both among the terminals and
     computers within an organization and among those in different
     organizations.

     Rapid electronic transport of digitized data requires electronic
     communication links that tie the elements together. These links are
     established, organized, and maintained by means of a layered series
     of procedures performing the many functions inherent in the
     communications process. The successful movement of digitized data
     depends upon the participants using identical or compatible
     procedures, or protocols.

     The DOD and NBS have each developed and promulgated a transport
     protocol as standard. The two protocols, however, are dissimilar and
     incompatible. The committee was called to resolve the differences
     between these protocols.

     The committee held its first meeting in August 1983 at the National
     Research Council in Washington, D.C. Following this two-day meeting
     the committee held five more two-day meetings, a three-day meeting,
     and a one-week workshop.

     The committee was briefed by personnel from both agencies. In
     addition, the committee heard from Jon Postel, University of Southern
     California's Information Sciences Institute; Dave Oran, Digital
     Equipment Corporation; Vinton Cerf, MCI; David Wood, The Mitre
     Corporation; Clair Miller, Honeywell, and Robert Follett, IBM,
     representing the Computer and Business Equipment Manufacturer's
     Association; and John Newman, Ultimate Corporation. In most cases
     the briefings were followed by discussion.

     The committee wishes to thank Philip Selvaggi of the Department of
     Defense and Robert Blanc of the NBS, Institute of Computer Sciences

and Technology, for their cooperation as their agency's liaison
representatives to the committee. The committee appreciates the
contributions and support of Richard B. Marsten, Executive Director
of the Board on Telecommunications -- Computer Applications (BOTCAP),
and Jerome D. Rosenberg, BOTCAP Senior Staff Officer and the
committee Study Director. We also wish to thank Lois A. Leak for her
expert administrative and secretarial support.

EXECUTIVE SUMMARY

Computer communication networks have become a very important part of
military and commercial operations. Indeed, the nation is becoming
dependent upon their efficiency and reliability, and the recent
proliferation of networks and their widespread use have emphasized
the importance of developing uniform conventions, or protocols, for
communication between computer systems. The Department of Defense
(DOD) and the National Bureau of Standards (NBS) have been actively
engaged in activities related to protocol standardization. This
report is concerned primarily with recommendations on protocol
standardization within the Department of Defense.

Department of Defense's Transmission Protocol

    The DOD's Defense Advanced Research Projects Agency (DARPA) has
    been conducting and supporting research on computer networks for
    over fifteen years (1). These efforts led to the development of
    modern packet-switched network design concepts. Transmission
    between computers is generally accomplished by packet switching
    using strict protocols for the control and exchange of messages.
    The Advanced Research Projects Agency network (ARPANET),
    implemented in the early 1970s, provided a testing ground for
    research on communications protocols. In 1978, after four years
    of development, the DOD promulgated versions of its Transmission
    Control Protocol (TCP) and an Internet Protocol (IP) and mandated
    their use as standards within the DOD. TCP is now widely used and
    accepted. These protocols meet the unique operational and
    functional requirements of the DOD, and any changes in the
    protocols are viewed with some trepidation by members of the
    department. DOD representatives have stated that standardizing
    TCP greatly increased the momentum within the DOD toward
    establishing interoperability between networks within the DOD.

International Standards Organization's Transport Protocol

    The NBS Institute for Computer Sciences and Technology (ICST), in
    cooperation with the DOD, many industrial firms, and the
    International Standards Organization (ISO), has developed a new
    international standard

    Transport Protocol (TP-4) and a new Internetwork Protocol (2).
    These protocols will soon be available as commercial products.
    Although in part derived from TCP, the new protocols are not
    compatible with TCP (3). The U.S. standards organizations are

supporting TP-4 in international operations, and the Department of
Commerce is proposing TP-4 as a Federal Information Processing
Standard (FIPS) for use by all federal agencies.

DOD OPERATIONAL AND TECHNICAL NEEDS

The DOD has unique needs that could be affected by the Transport
and Internet Protocol layers. Although all data networks must
have some of these capabilities, the DOD's needs for operational
readiness, mobilization, and war-fighting capabilities are
extreme. These needs include the following:

Survivability--Some networks must function, albeit at reduced
performance, after many nodes and links have been destroyed.

Security--Traffic patterns and data must be selectively
protected through encryption, access control, auditing, and
routing.

Precedence--Systems should adjust the quality of service on the
basis of priority of use; this includes a capability to preempt
services in cases of very high priority.

Robustness--The system must not fail or suffer much loss of
capability because of unpredicted situations, unexpected loads,
or misuse. An international crisis is the strongest test of
robustness, since the system must operate immediately and with
virtually full performance when an international situation
flares up unexpectedly.

Availability--Elements of the system needed for operational
readiness or fighting must be continuously available.

Interoperability--Different elements of the Department must be
able to "talk" to one another, often in unpredicted ways
between parties that had not planned to interoperate.

These operational needs reflect themselves into five technical or
managerial needs:

1.   Functional and operational specifications (that is, will
      the protocol designs meet the operational needs?);

2.   Maximum interoperability;

3.   Minimum procurement, development, and support costs;

> 4. Ease of transition to new protocols; and
>
> 5. Manageability and responsiveness to changing DOD
>   requirements.

These are the criteria against which DOD options for using the ISO transport and internet protocols should be evaluated.

Interoperability is a very important DOD need. Ideally, DOD networks would permit operators at any terminal to access or be accessed by applications in any computer. This would provide more network power for users, integration of independently developed systems, better use of resources, and increased survivability. To increase interoperability, the Office of the Secretary of Defense has mandated the use of TCP for the Defense Communication System's Defense Data Network (DDN), unless waivers are granted. In addition, the Defense Communication Agency (DCA) is establishing standards for three higher-level "utility" protocols for file transfer, terminal access, and electronic mail. Partly as a result of these actions, it has become clear that there is growing momentum toward accepting interoperability and a recognition that it is an important operational need.

It is very important, however, to recognize that functional interoperability is only achieved with full generality when two communication nodes can interoperate at all protocol levels. For the DOD the relevant levels are as follows:

> 1. Internet, using IP;
>
> 2. Transport, using TCP;
>
> 3. Utility, using file, terminal, or mail protocols; and
>
> 4. Specific applications that use the above protocols for
>   their particular purpose.

Accordingly, if a network is developed using one transport protocol, it would generally not be able to interoperate functionally with other networks using the same transport protocol unless both networks were also using the higher-level utility and application protocols. In evaluating whether or not to convert to TP-4 and in developing a transition plan, the following factors must be considered:

> The DOD contains numerous communities of interest whose
> principal need is to interoperate within their own members,

independently. Such communities generally have a specific,
well-defined mission. The DOD Intelligence Information System
(DODIIS) and the World Wide Military Command and Control System
(WWMCCS) are examples. Interoperability is needed primarily
between the higher layer applications programs initially unique
to each community of interest.

There are many different kinds of operations needed between
communities of interest. Examples of such operations are
headquarters' need for access to several subordinate
communities and the communities' need for some minimum
functional interoperability with each other (such as mail
exchange).

The need for functional interoperability can arise,
unexpectedly and urgently, at a time of crisis or when improved
management opportunities are discovered. Widespread
standardization of TP-4 and higher-level protocols can readily
help to achieve these needs. Often, special development of
additional applications that cost time and money will be
necessary.

The DOD needs functional interoperability with many important
external agencies that are committed to ISO standards: The
North Atlantic Treaty Organization (NATO), some intelligence
and security agencies, and other parts of the federal
government.

The same objectives that have prompted the use of standardized
protocols at higher-level headquarters will lead to their use
by tactical groups in the field.

SOME COMPARISONS

A detailed comparison of the DOD Transmission Control Protocol and
the ISO Transport Protocol indicates they are functionally
equivalent and provide essentially similar services. Because it
is clear that a great deal of care and experience in protocol
development have gone into generating the specifications for TP-4,
the committee is confident that TP-4 will meet military
requirements.

Although there are differences between the two protocols, they do
not compromise DOD requirements. And, although in several areas,
including the data transfer interface, flow control, connection
establishment, and out-of-band, services are provided in different
ways by the two protocols, neither seems intrinsically superior.

Thus, while existing applications may need to be modified somewhat
if moved from TCP to TP-4, new applications can be written to use
either protocol with a similar level of effort.

The TCP and TP-4 protocols are sufficiently equivalent in their
security-related properties in that there are no significant
technical points favoring the use of one over the other.

While TCP currently has the edge in maturity of implementation,
TP-4 is gaining rapidly due to the worldwide support for and
acceptance of the Open System Interconnection (OSI) international
standards. Experimental TCP implementations were completed in
1974 at Stanford University and BBN Communications Corporation.
Between 1974 and 1982 a large number of implementations were
produced. The Defense Advanced Research Projects Agency (ARPA)
network switched to a complete use of TCP in January 1983.
Operations have been satisfactory and its use is growing. A
number of TCP implementations are also in commercial use in
various private networks.

In contrast, TP-4 has not yet been implemented in any large
operational system. It has been tested experimentally, however,
and has received endorsement by many commercial vendors worldwide.
In addition, substantial portions of TP-4 have been demonstrated
at the National Computer Conference in July 1984.

The Internet Protocol (IP) part of the standards is not believed
to be a problem. The ISO IP is not as far along as TP-4, but it
is much less complex. The ISO IP, based very strongly on the DOD
IP, became a draft international standard in April 1984.

The rapidity of the progress in ISO and the results achieved over
the past two years have surprised even the supporters of
international standards. The reasons for this progress are
twofold: strong market demands stemming from the growing
integration of communications and data processing and the progress
in networking technology over the past years as the result of ARPA
and commercial developments.

Although the DOD networks have been a model upon which the ISO
transport standards have been built, the rest of the world is
adopting TP-4. Because the DOD represents a small fraction of the
market and because the United States supports the ISO standard, it
is not realistic to hope that TP-4 can be altered to conform with
TCP. This raises the question as to what action should be taken
by the DOD with respect to the ISO standard.

    SOME ECONOMIC CONSIDERATIONS

    The DOD has a large and growing commitment in operational TCP
    networks, and this will increase by 50 to 100 percent in the next
    eighteen months. This rate of investment will probably continue
    for the next five years for new systems and the upgrading of
    current ones. The current Military Network (MILNET) and Movement
    Information Network (MINET) systems are expanding and will shortly
    be combined. The Strategic Air Command Digital Information
    Network (SACDIN) and DODIIS are undergoing major upgrading. When
    these changes are completed, there are plans to upgrade the WWMCCS
    Intercomputer Network (WIN) and to add separate SECRET and TOP
    SECRET networks. There are plans to combine these six networks in
    the late 1980s, and they will become interoperable and multilevel
    secure using an advanced technology now under development. If
    these plans are implemented on schedule, a delay of several years
    in moving to TP-4 would mean that the DOD networks in the late
    1980s would be virtually all TCP-based. Subsequent conversion to
    international standards would be very expensive if hastily
    attempted in order to maintain established DOD interoperability
    and gain interoperability with a large body of users.

    As the Department of Defense policy recognizes, there are
    significant advantages in using commercial vendor products if they
    meet the department's operational needs. The major advantages are
    as follows:

        Costs to the DOD for development, production, and maintenance
        are significantly lower because (1) vendors spread the cost
        over a much larger user base, (2) commercial vendors are
        generally more efficient in their operations, and (3) vendors
        look for ways to improve their product to meet competition.

        The department generally gets more effective products because
        vendors integrate the protocol functions into their entire
        software and hardware product line. Thus the DOD may be able
        eventually to use commercial software products that are built
        on top of, and thereby take advantage of, the transport
        protocols.

        By depending on industry to manage the development and
        maintenance of products, the department can use its scarce
        management and technical resources on activities unique to its
        mission.

    Because the costs of transport and internet protocol development
    and maintenance are so intertwined with other factors, it is

        impossible to give a precise estimate of the savings that would be
        achieved by using commercial products. Savings will vary in
        individual cases. The marginal savings should range from 30 to 80
        percent.

    RECOMMENDATIONS

        The ISO protocols are now well specified but will not generally be
        commercially available for many months. Nevertheless, this
        committee believes that the principles on which they are based are
        well-established, and the protocols can be made to satisfy fully
        DOD's needs. The committee recommends that the DOD move toward
        adoption of TP-4 as costandard with TCP and toward exclusive use
        of TP-4.

        Transition to the use of the ISO standards, however, must be
        managed in a manner that will maintain DOD's operational
        capabilities and minimize risks. The timing of the transition is,
        therefore, a major concern.

        Descriptions of two options that take this requirement into
        account follow. A majority of the committee recommends the first
        option, while a minority favors the second. A third option--to
        defer action--is also described but not recommended.

        Option 1

            The first option is for the DOD to immediately modify its
            current transport policy statement to specify TP-4 as a
            costandard along with TCP. In addition, the DOD would develop
            a military specification for TP-4 that would also cover DOD
            requirements for discretionary options allowed under the NBS
            protocol specifications. Requests for proposals (RFPs) for new
            networks or major upgrades of existing networks would specify
            TP-4 as the preferred protocol. Contracts for TP-4 systems
            would be awarded only to contractors providing commercial
            products, except for unique cases.

            Existing networks that use TCP and new networks firmly
            committed to the use of TCP-based systems could continue to
            acquire implementations of TCP. The DOD should carefully
            review each case, however, to see whether it would be
            advantageous to delay or modify some of these acquisitions in
            order to use commercial TP-4 products. For each community of
            users it should be decided when it is operationally or

economically most advantageous to replace its current or
planned systems in order to conform to ISO standards without
excessively compromising continued operations.

United States government test facilities would be developed to
enable validation of TP-4 products (4). The Department of
Defense would either require that products be validated using
these test facilities or that they be certified by the vendor.
The test facilities could also be used to isolate multivendor
protocol compatibility problems. The existing NBS validation
tools should be used as the base for the DOD test facilities.

Because under this option networks based on both TCP and TP-4
would coexist for some time, several capabilities that
facilitate interoperability among networks would need to be
developed. The Department of Defense generally will not find
them commercially available. Examples are gateways among
networks or specialized hosts that provide services such as
electronic mail. The department would need to initiate or
modify development programs to provide these capabilities, and
a test and demonstration network would be required.

Option 2

Under Option 2 the Department of Defense would immediately
announce its intention to adopt TP-4 as a transport protocol
costandard with TCP after a satisfactory demonstration of its
suitability for use in military networks. A final commitment
would be deferred until the demonstration has been evaluated
and TP-4 is commercially available.

The demonstration should take at most eighteen months and
should involve development of TP-4 implementations and their
installation. This option differs from Option 1 primarily in
postponing the adoption of a TP-4 standard and, consequently,
the issuance of RFPs based on TP-4 until successful completion
of a demonstration. The department, however, should proceed
with those provisions of Option 1 that may be completed in
parallel with the demonstration. Early issuance of a TP-4
military specification, development of validation procedures,
and implementation of means for interoperability would be
particularly important in this regard.

Option 3

Under the third option the DOD would continue using TCP as the
accepted transport standard and defer any decision on the use
of TP-4 indefinitely. The department would be expected to stay
well informed on the development and use of the new protocol in
the commercial and international arena and, with the National
Bureau of Standards, work on means to transfer data between the
two protocol systems. Testing and evaluation of TP-4 standards
by NBS would continue. The DOD might eventually accommodate
both protocol systems in an evolutionary conversion to TP-4.

Comparison of Options

The committee believes that all three options equally satisfy
the functional objectives of the DOD, including matters of
security. It believes the two protocols are sufficiently
similar and no significant differences in performance are to be
expected if the chosen protocol implementation is of equal
quality and is optimized for the given environment.

The primary motivation for recommending Option 1 is to obtain
the benefits of standard commercial products in the
communication protocol area at an early date. Benefits include
smaller development, procurement, and support costs; more
timely updates; and a wider product availability. By
immediately committing to TP-4 as a costandard for new systems,
Option 1 minimizes the number of systems that have to be
converted eventually from TCP. The ability to manage the
transition is better than with Option 2 since the number of
systems changed would be smaller and the time duration of mixed
TCP and TP-4 operation would be shorter. Interoperability with
external systems (NATO, government, commercial), which
presumably will also use TP-4, would be brought about more
quickly. Option 1 involves greater risk, however, since it
commits to a new approach without as complete a demonstration
of its viability.

As with Option 1, a primary benefit of following Option 2 would
be obtaining the use of standard commercial products. Unit
procurement costs probably would be lower than with Option 1
because the commercial market for TP-4 will have expanded
somewhat by the time DOD would begin to buy TP-4 products.
Risk is smaller, compared to Option 1, because testing and
demonstration of the suitability for military use will have
preceded the commitment to the ISO protocols. Transition and
support costs would be higher than for Option 1, however,

because more networks and systems would already have been
implemented with TCP. Also this is perhaps the most difficult
option to manage since the largest number of system conversions
and the longest interval of mixed TCP and TP-4 operations would
occur. In addition, interoperability with external networks
through standardization would be delayed.

The principal benefit of exercising Option 3 would be the
elimination of transition cost and the risk of faulty system
behavior and delay. It would allow the most rapid achievement
of full internal interoperability among DOD systems.
Manageability should be good because only one set of protocols
would be in use (one with which the DOD already has much
experience), and because the DOD would be in complete control
of system evolution. Procurement costs for TCP systems would
remain high compared with standard ISO protocol products,
however, and availability of implementations for new systems
and releases would remain limited. External interoperability
with non-DOD systems would be limited and inefficient.

In summary, Option 1 provides the most rapid path toward the
use of commercial products and interoperability with external
systems. Option 2 reduces the risk but involves somewhat
greater delay and expense. Option 3 involves the least risk
and provides the quickest route to interoperability within the
Defense Department at the least short-term cost. These are,
however, accompanied by penalties of incompatibility with NATO
and other external systems and higher life-cycle costs.

NOTES:

   (1) The Advanced Research Projects Agency (ARPA) was reorganized
        and became the Defense Advanced Research Projects Agency
        (DARPA) in 1973.

   (2) The ISO Transport Protocol and ISO Internetwork Protocol
        became Draft International Standards in September 1983 and
        April 1984, respectively. Commercial vendors normally
        consider Draft International Standards to be ready for
        implementation.

   (3) Except where noted, the abbreviation TCP generally refers to
        both the DOD's Transmission Control Protocol and its Internet
        Protocol. Similarly, the abbreviation TP-4 refers to both
        the ISO Transport Protocol class 4 and its Internetwork
        Protocol. (Transport Protocol classes 0 to 3 are used for
        special purposes not related to those of this study.)

(4) Validation means a systematic and thorough state-of-the-art
     testing of the products to assure that all technical
     specifications are being achieved.

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