                   On the Design of Application Protocols

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Abstract

   This memo describes the design principles for the Blocks eXtensible
   eXchange Protocol (BXXP). BXXP is a generic application protocol
   framework for connection-oriented, asynchronous interactions. The
   framework permits simultaneous and independent exchanges within the
   context of a single application user-identity, supporting both
   textual and binary messages.

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1. A Problem 19 Years in the Making

   SMTP [1] is close to being the perfect application protocol: it
   solves a large, important problem in a minimalist way. It's simple
   enough for an entry-level implementation to fit on one or two screens
   of code, and flexible enough to form the basis of very powerful
   product offerings in a robust and competitive market. Modulo a few
   oddities (e.g., SAML), the design is well conceived and the resulting
   specification is well-written and largely self-contained. There is
   very little about good application protocol design that you can't
   learn by reading the SMTP specification.

   Unfortunately, there's one little problem: SMTP was originally
   published in 1981 and since that time, a lot of application protocols
   have been designed for the Internet, but there hasn't been a lot of
   reuse going on. You might expect this if the application protocols
   were all radically different, but this isn't the case: most are
   surprisingly similar in their functional behavior, even though the
   actual details vary considerably.

   In late 1998, as Carl Malamud and I were sitting down to review the
   Blocks architecture, we realized that we needed to have a protocol
   for exchanging Blocks. The conventional wisdom is that when you need
   an application protocol, there are four ways to proceed:

   1. find an existing exchange protocol that (more or less) does what
      you want;

   2. define an exchange model on top of the world-wide web
      infrastructure that (more or less) does what you want;

   3. define an exchange model on top of the electronic mail
      infrastructure that (more or less) does what you want; or,

   4. define a new protocol from scratch that does exactly what you
      want.

   An engineer can make reasoned arguments about the merits of each of
   the these approaches. Here's the process we followed...

   The most appealing option is to find an existing protocol and use
   that. (In other words, we'd rather "buy" than "make".) So, we did a
   survey of many existing application protocols and found that none of
   them were a good match for the semantics of the protocol we needed.

   For example, most application protocols are oriented toward
   client/server behavior, and emphasize the client pulling data from
   the server; in contrast with Blocks, a client usually pulls data from

the server, but it also may request the server to asynchronously push
(new) data to it. Clearly, we could mutate a protocol such as FTP
[2] or SMTP into what we wanted, but by the time we did all that, the
base protocol and our protocol would have more differences than
similarities. In other words, the cost of modifying an off-the-shelf
implementation becomes comparable with starting from scratch.

Another approach is to use HTTP [3] as the exchange protocol and
define the rules for data exchange over that. For example, IPP [4]
(the Internet Printing Protocol) uses this approach. The basic idea
is that HTTP defines the rules for exchanging data and then you
define the data's syntax and semantics. Because you inherit the
entire HTTP infrastructure (e.g., HTTP's authentication mechanisms,
caching proxies, and so on), there's less for you to have to invent
(and code!). Or, conversely, you might view the HTTP infrastructure
as too helpful. As an added bonus, if you decide that your protocol
runs over port 80, you may be able to sneak your traffic past older
firewalls, at the cost of port 80 saturation.

HTTP has many strengths: it's ubiquitous, it's familiar, and there
are a lot of tools available for developing HTTP-based systems.
Another good thing about HTTP is that it uses MIME [5] for encoding
data.

Unfortunately for us, even with HTTP 1.1 [6], there still wasn't a
good fit. As a consequence of the highly-desirable goal of
maintaining compatibility with the original HTTP, HTTP's framing
mechanism isn't flexible enough to support server-side asynchronous
behavior and its authentication model isn't similar to other Internet
applications.

Mapping IPP onto HTTP 1.1 illustrates the former issue. For example,
the IPP server is supposed to signal its client when a job completes.
Since the HTTP client must originate all requests and since the
decision to close a persistent connection in HTTP is unilateral, the
best that the IPP specification can do is specify this functionality
in a non-deterministic fashion.

Further, the IPP mapping onto HTTP shows that even subtle shifts in
behavior have unintended consequences. For example, requests in IPP
are typically much larger than those seen by many HTTP server
implementations -- resulting in oddities in many HTTP servers (e.g.,
requests are sometimes silently truncated). The lesson is that
HTTP's framing mechanism is very rigid with respect to its view of
the request/response model.

   Lastly, given our belief that the port field of the TCP header isn't
   a constant 80, we were immune to the seductive allure of wanting to
   sneak our traffic past unwary site administrators.

   The third choice, layering the protocol on top of email, was
   attractive. Unfortunately, the nature of our application includes a
   lot of interactivity with relatively small response times. So, this
   left us the final alternative: defining a protocol from scratch.

   To begin, we figured that our requirements, while a little more
   stringent than most, could fit inside a framework suitable for a
   large number of future application protocols. The trick is to avoid
   the kitchen-sink approach. (Dave Clark has a saying: "One of the
   roles of architecture is to tell you what you can't do.")

2. You can Solve Any Problem...

      ...if you're willing to make the problem small enough.

   Our most important step is to limit the problem to application
   protocols that exhibit certain features:

   o they are connection-oriented;

   o they use requests and responses to exchange messages; and,

   o they allow for asynchronous message exchange.

   Let's look at each, in turn.

   First, we're only going to consider connection-oriented application
   protocols (e.g., those that work on top of TCP [7]). Another branch
   in the taxonomy, connectionless, consists of those that don't want
   the delay or overhead of establishing and maintaining a reliable
   stream. For example, most DNS [8] traffic is characterized by a
   single request and response, both of which fit within a single IP
   datagram. In this case, it makes sense to implement a basic
   reliability service above the transport layer in the application
   protocol itself.

   Second, we're only going to consider message-oriented application
   protocols. A "message" -- in our lexicon -- is simply structured
   data exchanged between loosely-coupled systems. Another branch in
   the taxonomy, tightly-coupled systems, uses remote procedure calls as
   the exchange paradigm. Unlike the connection-oriented/connectionless
   dichotomy, the issue of loosely- or tightly-coupled systems is
   similar to a continuous spectrum. Fortunately, the edges are fairly
   sharp.

   For example, NFS [9] is a tightly-coupled system using RPCs. When
   running in a properly-configured LAN, a remote disk accessible via
   NFS is virtually indistinguishable from a local disk. To achieve
   this, tightly-coupled systems are highly concerned with issues of
   latency. Hence, most (but not all) tightly-coupled systems use
   connection-less RPC mechanisms; further, most tend to be implemented
   as operating system functions rather than user-level programs. (In
   some environments, the tightly-coupled systems are implemented as
   single-purpose servers, on hardware specifically optimized for that
   one function.)

   Finally, we're going to consider the needs of application protocols
   that exchange messages asynchronously. The classic client/server
   model is that the client sends a request and the server sends a

response. If you think of requests as "questions" and responses as
"answers", then the server answers only those questions that it's
asked and it never asks any questions of its own. We'll need to
support a more general model, peer-to-peer. In this model, for a
given transaction one peer might be the "client" and the other the
"server", but for the next transaction, the two peers might switch
roles.

It turns out that the client/server model is a proper subset of the
peer-to-peer model: it's acceptable for a particular application
protocol to dictate that the peer that establishes the connection
always acts as the client (initiates requests), and that the peer
that listens for incoming connections always acts as the server
(issuing responses to requests).

There are quite a few existing application domains that don't fit our
requirements, e.g., nameservice (via the DNS), fileservice (via NFS),
multicast-enabled applications such as distributed video
conferencing, and so on. However, there are a lot of application
domains that do fit these requirements, e.g., electronic mail, file
transfer, remote shell, and the world-wide web. So, the bet we are
placing in going forward is that there will continue to be reasons
for defining protocols that fit within our framework.

3. Protocol Mechanisms

   The next step is to look at the tasks that an application protocol
   must perform and how it goes about performing them. Although an
   exhaustive exposition might identify a dozen (or so) areas, the ones
   we're interested in are:

   o framing, which tells how the beginning and ending of each message
      is delimited;

   o encoding, which tells how a message is represented when exchanged;

   o reporting, which tells how errors are described;

   o asynchrony, which tells how independent exchanges are handled;

   o authentication, which tells how the peers at each end of the
      connection are identified and verified; and,

   o privacy, which tells how the exchanges are protected against
      third-party interception or modification.

   A notable absence in this list is naming -- we'll explain why later
   on.

3.1 Framing

   There are three commonly used approaches to delimiting messages:
   octet-stuffing, octet-counting, and connection-blasting.

   An example of a protocol that uses octet-stuffing is SMTP. Commands
   in SMTP are line-oriented (each command ends in a CR-LF pair). When
   an SMTP peer sends a message, it first transmits the "DATA" command,
   then it transmits the message, then it transmits a "." (dot) followed
   by a CR-LF. If the message contains any lines that begin with a dot,
   the sending SMTP peer sends two dots; similarly, when the other SMTP
   peer receives a line that begins with a dot, it discards the dot,
   and, if the line is empty, then it knows it's received the entire
   message. Octet-stuffing has the property that you don't need the
   entire message in front of you before you start sending it.
   Unfortunately, it's slow because both the sender and receiver must
   scan each line of the message to see if they need to transform it.

   An example of a protocol that uses octet-counting is HTTP. Commands
   in HTTP consist of a request line followed by headers and a body. The
   headers contain an octet count indicating how large the body is. The
   properties of octet-counting are the inverse of octet-stuffing:

before you can start sending a message you need to know the length of
the whole message, but you don't need to look at the content of the
message once you start sending or receiving.

An example of a protocol that uses connection-blasting is FTP.
Commands in FTP are line-oriented, and when it's time to exchange a
message, a new TCP connection is established to transmit the message.
Both octet-counting and connection-blasting have the property that
the messages can be arbitrary binary data; however, the drawback of
the connection-blasting approach is that the peers need to
communicate IP addresses and TCP port numbers, which may be
"transparently" altered by NATS [10] and network bugs. In addition,
if the messages being exchanged are small (say less than 32k), then
the overhead of establishing a connection for each message
contributes significant latency during data exchange.

3.2 Encoding

There are many schemes used for encoding data (and many more encoding
schemes have been proposed than are actually in use). Fortunately,
only a few are burning brightly on the radar.

The messages exchanged using SMTP are encoded using the 822-style
[11]. The 822-style divides a message into textual headers and an
unstructured body. Each header consists of a name and a value and is
terminated with a CR-LF pair. An additional CR-LF separates the
headers from the body.

It is this structure that HTTP uses to indicate the length of the
body for framing purposes. More formally, HTTP uses MIME, an
application of the 822-style to encode both the data itself (the
body) and information about the data (the headers). That is,
although HTTP is commonly viewed as a retrieval mechanism for HTML
[12], it is really a retrieval mechanism for objects encoded using
MIME, most of which are either HTML pages or referenced objects such
as GIFs.

3.3 Reporting

An application protocol needs a mechanism for conveying error
information between peers. The first formal method for doing this
was defined by SMTP's "theory of reply codes". The basic idea is
that an error is identified by a three-digit string, with each
position having a different significance:

the first digit: indicating success or failure, either permanent or
   transient;

   the second digit: indicating the part of the system reporting the
      situation (e.g., the syntax analyzer); and,

   the third digit: identifying the actual situation.

   Operational experience with SMTP suggests that the range of error
   conditions is larger than can be comfortably encoded using a three-
   digit string (i.e., you can report on only 10 different things going
   wrong for any given part of the system). So, [13] provides a
   convenient mechanism for extending the number of values that can
   occur in the second and third positions.

   Virtually all of the application protocols we've discussed thus far
   use the three-digit reply codes, although there is less coordination
   between the designers of different application protocols than most
   would care to admit. (A variation on the theory of reply codes is
   employed by IMAP [14] which provides the same information using a
   different syntax.)

   In addition to conveying a reply code, most application protocols
   also send a textual diagnostic suitable for human, not machine,
   consumption. (More accurately, the textual diagnostic is suitable
   for people who can read a widely used variant of the English
   language.) Since reply codes reflect both positive and negative
   outcomes, there have been some innovative uses made for the text
   accompanying positive responses, e.g., prayer wheels [39].
   Regardless, some of the more modern application protocols include a
   language localization parameter for the diagnostic text.

   Finally, since the introduction of reply codes in 1981, two
   unresolved criticisms have been raised:

   o a reply code is used both to signal the outcome of an operation
      and a change in the application protocol's state; and,

   o a reply code doesn't specify whether the associated textual
      diagnostic is destined for the end-user, administrator, or
      programmer.

3.4 Asynchrony

   Few application protocols today allow independent exchanges over the
   same connection. In fact, the more widely implemented approach is to
   allow pipelining, e.g., command pipelining [15] in SMTP or persistent
   connections in HTTP 1.1. Pipelining allows a client to make multiple
   requests of a server, but requires the requests to be processed
   serially. (Note that a protocol needs to explicitly provide support
   for pipelining, since, without explicit guidance, many implementors

produce systems that don't handle pipelining properly; typically, an
error in a request causes subsequent requests in the pipeline to be
discarded).

Pipelining is a powerful method for reducing network latency. For
example, without persistent connections, HTTP's framing mechanism is
really closer to connection-blasting than octet-counting, and it
enjoys the same latency and efficiency problems.

In addition to reducing network latency (the pipelining effect),
asynchrony also reduces server latency by allowing multiple requests
to be processed by multi-threaded implementations. Note that if you
allow any form of asynchronous exchange, then support for parallelism
is also required, because exchanges aren't necessarily occurring
under the synchronous direction of a single peer.

Unfortunately, when you allow parallelism, you also need a flow
control mechanism to avoid starvation and deadlock. Otherwise, a
single set of exchanges can monopolize the bandwidth provided by the
transport layer. Further, if a peer is resource-starved, then it may
not have enough buffers to receive a message and deadlock results.

Flow control is typically implemented at the transport layer. For
example, TCP uses sequence numbers and a sliding window: each
receiver manages a sliding window that indicates the number of data
octets that may be transmitted before receiving further permission.
However, it's now time for the second shoe to drop: segmentation. If
you do flow control then you also need a segmentation mechanism to
fragment messages into smaller pieces before sending and then re-
assemble them as they're received.

Both flow control and segmentation have an impact on how the protocol
does framing. Before we defined framing as "how to tell the
beginning and end of each message" -- in addition, we need to be able
to identify independent messages, send messages only when flow
control allows us to, and segment them if they're larger than the
available window (or too large for comfort).

Segmentation impacts framing in another way -- it relaxes the octet-
counting requirement that you need to know the length of the whole
message before sending it. With segmentation, you can start sending
segments before the whole message is available. In HTTP 1.1 you can
"chunk" (segment) data to get this advantage.

3.5 Authentication

   Perhaps for historical (or hysterical) reasons, most application
   protocols don't do authentication. That is, they don't authenticate
   the identity of the peers on the connection or the authenticity of
   the messages being exchanged. Or, if authentication is done, it is
   domain-specific for each protocol. For example, FTP and HTTP use
   entirely different models and mechanisms for authenticating the
   initiator of a connection. (Independent of mainstream HTTP, there is
   a little-used variant [16] that authenticates the messages it
   exchanges.)

   A large part of the problem is that different security mechanisms
   optimize for strength, scalability, or ease of deployment. So, a few
   years ago, SASL [17] (the Simple Authentication and Security Layer)
   was developed to provide a framework for authenticating protocol
   peers. SASL let's you describe how an authentication mechanism
   works, e.g., an OTP [18] (One-Time Password) exchange. It's then up
   to each protocol designer to specify how SASL exchanges are
   generically conveyed by the protocol. For example, [19] explains how
   SASL works with SMTP.

   A notable exception to the SASL bandwagon is HTTP, which defines its
   own authentication mechanisms [20]. There is little reason why SASL
   couldn't be introduced to HTTP, although to avoid certain race-
   conditions, the persistent connection mechanism of HTTP 1.1 must be
   used.

   SASL has an interesting feature in that in addition to explicit
   protocol exchanges to authenticate identity, it can also use implicit
   information provided from the layer below. For example, if the
   connection is running over IPsec [21], then the credentials of each
   peer are known and verified when the TCP connection is established.

   Finally, as its name implies, SASL can do more than authentication --
   depending on which SASL mechanism is in use, message integrity or
   privacy services may also be provided.

3.6 Privacy

   HTTP is the first widely used protocol to make use of a transport
   security protocol to encrypt the data sent on the connection. The
   current version of this mechanism, TLS [22], is available to all
   application protocols, e.g., SMTP and ACAP [23] (the Application
   Configuration Access Protocol).

   The key difference between the original mechanism and TLS, is one of
   provisioning not technology. In the original approach to
   provisioning, a world-wide web server listens on two ports (one for
   plaintext traffic and the other for secured traffic); in contrast, by
   today's conventions, a server implementing an application protocol
   that is specified as TLS-enabled (e.g., [24] and [25]) listens on a
   single port for plaintext traffic, and, once a connection is
   established, the use of TLS on that connection is negotiable.

   Finally, note that both SASL and TLS are about "transport security"
   not "object security". What this means is that they focus on
   providing security properties for the actual communication, they
   don't provide any security properties for the data exchanged
   independent of the communication.

3.7 Let's Recap

   Let's briefly compare the properties of the three main connection-
   oriented application protocols in use today:

Mechanism	ESMTP	FTP	HTTP1.1
Framing	stuffing	blasting	counting
Encoding	822-style	binary	MIME
Reporting	3-digit	3-digit	3-digit
Asynchrony	pipelining	none	pipelining and chunking
Authentication	SASL	user/pass	user/pass
Privacy	SASL or TLS	none	TLS (nee SSL)

   Note that the username/password mechanisms used by FTP and HTTP are
   entirely different with one exception: both can be termed a
   "username/password" mechanism.

   These three choices are broadly representative: as more protocols are
   considered, the patterns are reinforced. For example, POP [26] uses
   octet-stuffing, but IMAP uses octet-counting, and so on.

4. Protocol Properties

   When we design an application protocol, there are a few properties
   that we should keep an eye on.

4.1 Scalability

   A well-designed protocol is scalable.

   Because few application protocols support asynchrony, a common trick
   is for a program to open multiple simultaneous connections to a
   single destination. The theory is that this reduces latency and
   increases throughput. The reality is that both the transport layer
   and the server view each connection as an independent instance of the
   application protocol, and this causes problems.

   In terms of the transport layer, TCP uses adaptive algorithms to
   efficiently transmit data as networks conditions change. But what
   TCP learns is limited to each connection. So, if you have multiple
   TCP connections, you have to go through the same learning process
   multiple times -- even if you're going to the same host. Not only
   does this introduce unnecessary traffic spikes into the network,
   because TCP uses a slow-start algorithm when establishing a
   connection, the program still sees additional latency. To deal with
   the fact that a lack of asynchrony in application protocols causes
   implementors to make sloppy use of the transport layer, network
   protocols are now provisioned with increasing sophistication, e.g.,
   RED [27]. Further, suggestions are also being considered for
   modification of TCP implementations to reduce concurrent learning,
   e.g., [28].

   In terms of the server, each incoming connection must be dispatched
   and (probably) authenticated against the same resources.
   Consequently, server overhead increases based on the number of
   connections established, rather than the number of remote users. The
   same issues of fairness arise: it's much harder for servers to
   allocate resources on a per-user basis, when a user can cause an
   arbitrary number of connections to pound on the server.

   Another important aspect of scalability to consider is the relative
   numbers of clients and servers. (This is true even in the peer-to-
   peer model, where a peer can act both in the client and server role.)
   Typically, there are many more client peers than server peers. In
   this case, functional requirements should be shifted from the servers
   onto the clients. The reason is that a server is likely to be
   interacting with multiple clients and this functional shift makes it
   easier to scale.

4.2 Efficiency

   A well-designed protocol is efficient.

   For example, although a compelling argument can be made than octet-
   stuffing leads to more elegant implementations than octet-counting,
   experience shows that octet-counting consumes far fewer cycles.

   Regrettably, we sometimes have to compromise efficiency in order to
   satisfy other properties. For example, 822 (and MIME) use textual
   headers. We could certainly define a more efficient representation
   for the headers if we were willing to limit the header names and
   values that could be used. In this case, extensibility is viewed as
   more important than efficiency. Of course, if we were designing a
   network protocol instead of an application protocol, then we'd make
   the trade-offs using a razor with a different edge.

4.3 Simplicity

   A well-designed protocol is simple.

   Here's a good rule of thumb: a poorly-designed application protocol
   is one in which it is equally as "challenging" to do something basic
   as it is to do something complex. Easy things should be easy to do
   and hard things should be harder to do. The reason is simple: the
   pain should be proportional to the gain.

   Another rule of thumb is that if an application protocol has two ways
   of doing the exact same thing, then there's a problem somewhere in
   the architecture underlying the design of the application protocol.

   Hopefully, simple doesn't mean simple-minded: something that's well-
   designed accommodates everything in the problem domain, even the
   troublesome things at the edges. What makes the design simple is
   that it does this in a consistent fashion. Typically, this leads to
   an elegant design.

4.4 Extensibility

   A well-designed protocol is extensible.

   As clever as application protocol designers are, there are likely to
   be unforeseen problems that the application protocol will be asked to
   solve. So, it's important to provide the hooks that can be used to
   add functionality or customize behavior. This means that the
   protocol is evolutionary, and there must be a way for implementations
   reflecting different steps in the evolutionary path to negotiate
   which extensions will be used.

But, it's important to avoid falling into the extensibility trap: the hooks provided should not be targeted at half-baked future requirements. Above all, the hooks should be simple.

Of course good design goes a long way towards minimizing the need for extensibility. For example, although SMTP initially didn't have an extension framework, it was only after ten years of experience that its excellent design was altered. In contrast, a poorly-designed protocol such as Telnet [29] can't function without being built around the notion of extensions.

4.5 Robustness

A well-designed protocol is robust.

Robustness and efficiency are often at odds. For example, although defaults are useful to reduce packet sizes and processing time, they tend to encourage implementation errors.

Counter-intuitively, Postel's robustness principle ("be conservative in what you send, liberal in what you accept") often leads to deployment problems. Why? When a new implementation is initially fielded, it is likely that it will encounter only a subset of existing implementations. If those implementations follow the robustness principle, then errors in the new implementation will likely go undetected. The new implementation then sees some, but not widespread deployment. This process repeats for several new implementations. Eventually, the not-quite-correct implementations run into other implementations that are less liberal than the initial set of implementations. The reader should be able to figure out what happens next.

Accordingly, explicit consistency checks in a protocol are very useful, even if they impose implementation overhead.

5. The BXXP Framework

   Finally, we get to the money shot: here's what we did.

   We defined an application protocol framework called BXXP (the Blocks
   eXtensible eXchange Protocol). The reason it's a "framework" instead
   of an application protocol is that we provide all the mechanisms
   discussed earlier without actually specifying the kind of messages
   that get exchanged. So, when someone else needs an application
   protocol that requires connection-oriented, asynchronous
   interactions, they can start with BXXP. It's then their
   responsibility to define the last 10% of the application protocol,
   the part that does, as we say, "the useful work".

   So, what does BXXP look like?

```
        Mechanism  BXXP
      --------------  ---------------------------------------
          Framing  counting, with a trailer

         Encoding  MIME, defaulting to text/xml

        Reporting  3-digit and localized textual diagnostic

       Asynchrony  channels

   Authentication  SASL

          Privacy  SASL or TLS
```

5.1 Framing and Encoding

   Framing in BXXP looks a lot like SMTP or HTTP: there's a command line
   that identifies the beginning of the frame, then there's a MIME
   object (headers and body). Unlike SMTP, BXXP uses octet-counting,
   but unlike HTTP, the command line is where you find the size of the
   payload. Finally, there's a trailer after the MIME object to aid in
   detecting framing errors.

   Actually, the command line for BXXP has a lot of information, it
   tells you:

   o what kind of message is in this frame;

   o whether there's more to the message than just what's in this frame
      (a continuation flag);

    o how to distinguish the message contained in this frame from other
       messages (a message number);

    o where the payload occurs in the sliding window (a sequence number)
       along with how many octets are in the payload of this frame; and,

    o which part of the application should get the message (a channel
       number).

       (The command line is textual and ends in a CR-LF pair, and the
       arguments are separated by a space.)

Since you need to know all this stuff to process a frame, we put it
all in one easy to parse location. You could probably devise a more
efficient encoding, but the command line is a very small part of the
frame, so you wouldn't get much bounce from optimizing it. Further,
because framing is at the heart of BXXP, the frame format has several
consistency checks that catch the majority of programming errors.
(The combination of a sequence number, an octet count, and a trailer
allows for very robust error detection.)

Another trick is in the headers: because the command line contains
all the framing information, the headers may contain minimal MIME
information (such as Content-Type). Usually, however, the headers
are empty. That's because the BXXP default payload is XML [30].
(Actually, a "Content-Type: text/xml" with binary transfer encoding).

We chose XML as the default because it provides a simple mechanism
for nested, textual representations. (Alas, the 822-style encoding
doesn't easily support nesting.) By design, XML's nature isn't
optimized for compact representations. That's okay because we're
focusing on loosely-coupled systems and besides there are efficient
XML parsers available. Further, there's a fair amount of anecdotal
experience -- and we'll stress the word "anecdotal" -- that if you
have any kind of compression (either at the link-layer or during
encryption), then XML encodings squeeze down nicely.

Even so, use of XML is probably the most controversial part of BXXP.
After all, there are more efficient representations around. We
agree, but the real issue isn't efficiency, it's ease of use: there
are a lot of people who grok the XML thing and there are a lot of XML
tools out there. The pain of recreating this social infrastructure
far outweighs any benefits of devising a new representation. So, if
the "make" option is too expensive, is there something else we can
"buy" besides XML? Well, there's ASN.1/BER (just kidding).

In the early days of the SNMP [31], which does use ASN.1, the same
issues arose. In the end, the working group agreed that the use of
ASN.1 for SNMP was axiomatic, but not because anyone thought that
ASN.1 was the most efficient, or the easiest to explain, or even well
liked. ASN.1 was given axiomatic status because the working group
decided it was not going to spend the next three years explaining an
alternative encoding scheme to the developer community.

So -- and we apologize for appealing to dogma -- use of XML as the
favored encoding scheme in BXXP is axiomatic.

5.2 Reporting

We use 3-digit error codes, with a localized textual diagnostic.
(Each peer specifies a preferred ordering of languages.)

In addition, the reply to a message is flagged as either positive or
negative. This makes it easy to signal success or failure and allow
the receiving peer some freedom in the amount of parsing it wants to
do on failure.

5.3 Asynchrony

Despite the lessons of SMTP and HTTP, there isn't a lot of field
experience to rely on when designing the asynchrony features of BXXP.
(Actually, there were several efforts in 1998 related to application
layer framing, e.g., [32], but none appear to have achieved orbit.)

So, here's what we did: frames are exchanged in the context of a
"channel". Each channel has an associated "profile" that defines the
syntax and semantics of the messages exchanged over a channel.

Channels provide both an extensibility mechanism for BXXP and the
basis for parallelism. Remember the last parameter in the command
line of a BXXP frame? The "part of the application" that gets the
message is identified by a channel number.

A profile is defined according to a "Profile Registration" template.
The template defines how the profile is identified (using a URI
[33]), what kind of messages get exchanged, along with the syntax and
semantics of those messages. When you create a channel, you identify
a profile and maybe piggyback your first message. If the channel is
successfully created, you get back a positive response; otherwise,
you get back a negative response explaining why.

Perhaps the easiest way to see how channels provide an extensibility
mechanism is to consider what happens when a session is established.
Each BXXP peer immediately sends a greeting on channel zero

identifying the profiles that each support. (Channel 0 is used for
channel management -- it's automatically created when a session is
opened.) If you want transport security, the very first thing you do
is to create a channel that negotiates transport security, and, once
the channel is created, you tell it to do its thing. Next, if you
want to authenticate, you create a channel that performs user
authentication, and, once the channel is created, you tell it to get
busy. At this point, you create one or more channels for data
exchange. This process is called "tuning"; once you've tuned the
session, you start using the data exchange channels to do "the useful
work".

The first channel that's successfully started has a trick associated
with it: when you ask to start the channel, you're allowed to specify
a "service name" that goes with it. This allows a server with
multiple configurations to select one based on the client's
suggestion. (A useful analogy is HTTP 1.1's "Host:" header.) If the
server accepts the "service name", then this configuration is used
for the rest of the session.

To allow parallelism, BXXP allows you to use multiple channels
simultaneously. Each channel processes messages serially, but there
are no constraints on the processing order for different channels.
So, in a multi-threaded implementation, each channel maps to its own
thread.

This is the most general case, of course. For one reason or another,
an implementor may not be able to support this. So, BXXP allows for
both positive and negative replies when a message is sent. So, if
you want the classic client/server model, the client program should
simply reject any new message sent by the server. This effectively
throttles any asynchronous messages from the server.

Of course, we now need to provide mechanisms for segmentation and
flow control. For the former, we just put a "continuation" or "more
to come" flag in the command line for the frame. For the latter, we
introduced the notion of a "transport mapping".

What this means is that BXXP doesn't directly define how it sits of
top of TCP. Instead, it lists a bunch of requirements for how a
transport service needs to support a BXXP session. Then, in a
separate document, we defined how you can use TCP to meet these
requirements.

This second document pretty much says "use TCP directly", except that
it introduces a flow control mechanism for multiplexing channels over
a single TCP connection. The mechanism we use is the same one used

by TCP (sequence numbers and a sliding window). It's proven, and can
be trivially implemented by a minimal implementation of BXXP.

The introduction of flow control is a burden from an implementation
perspective -- although TCP's mechanism is conceptually simple, an
implementor must take great care. For example, issues such as
priorities, queue management, and the like should be addressed.
Regardless, we feel that the benefits of allowing parallelism for
intra-application streams is worth it. (Besides, our belief is that
few application implementors will actually code the BXXP framework
directly -- rather, we expect them to use third-party packages that
implement BXXP.)

5.4 Authentication

We use SASL. If you successfully authenticate using a channel, then
there is a single user identity for each peer on that session (i.e.,
authentication is per-session, not per-channel). This design
decision mandates that each session correspond to a single user
regardless of how many channels are open on that session. One reason
why this is important is that it allows service provisioning, such as
quality of service (e.g., as in [34]) to be done on a per-user
granularity.

5.5 Privacy

We use SASL and TLS. If you successfully complete a transport
security negotiation using a channel, then all traffic on that
session is secured (i.e., confidentiality is per-session, not per-
channel, just like authentication).

We defined a BXXP profile that's used to start the TLS engine.

5.6 Things We Left Out

We purposefully excluded two things that are common to most
application protocols: naming and authorization.

Naming was excluded from the framework because, outside of URIs,
there isn't a commonly accepted framework for naming things. To our
view, this remains a domain-specific problem for each application
protocol. Maybe URIs are appropriate in the context of a
particularly problem domain, maybe not. So, when an application
protocol designer defines their own profile to do "the useful work",
they'll have to deal with naming issues themselves. BXXP provides a
mechanism for identifying profiles and binding them to channels. It's
up to you to define the profile and use the channel.

Similarly, authorization was explicitly excluded from the framework. Every approach to authorization we've seen uses names to identify principals (i.e., targets and subjects), so if a framework doesn't include naming, it can't very well include authorization.

Of course, application protocols do have to deal with naming and authorization -- those are two of the issues addressed by the applications protocol designer when defining a profile for use with BXXP.

5.7 From Framework to Protocol

So, how do you go about using BXXP? To begin, call it "BEEP", not "BXXP" (we'll explain why momentarily).

First, get the BEEP core specification [35] and read it. Next, define your own profile. Finally, get one of the open source SDKs (in C, Java, or Tcl) and start coding.

The BEEP specification defines several profiles itself: a channel management profile, a family of profiles for SASL, and a transport security profile. In addition, there's a second specification [36] that explains how a BEEP session maps onto a single TCP connection.

For a complete example of an application protocol defined using BEEP, look at reliable syslog [37]. This document exemplifies the formula:

application protocol = BEEP + 1 or more profiles
                       + authorization policies
                       + provisioning rules (e.g., use of SRV RRs [38])

6. BXXP is now BEEP

   We started work on BXXP in the fall of 1998. The IETF formed a
   working group on BXXP in the summer of 2000. Although the working
   group made some enhancements to BXXP, three are the most notable:

   o The payload default is "application/octet-stream". This is
      primarily for wire-efficiency -- if you care about wire-
      efficiency, then you probably wouldn't be using "text/xml"...

   o One-to-many exchanges are supported (the client sends one message
      and the server sends back many replies).

   o BXXP is now called BEEP (more comic possibilities).

7. Security Considerations

   Consult Section [35]'s Section 8 for a discussion of BEEP-related
   security issues.

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Author's Address

   Marshall T. Rose
   Dover Beach Consulting, Inc.
   POB 255268
   Sacramento, CA 95865-5268
   US

   Phone: +1 916 483 8878
   EMail: mrose@dbc.mtview.ca.us