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| **UDAParts** |
| **Development guide for SocketPro asynchronous communication framework** |
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| **support@udaparts.com**  **11/16/2016** |

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# Version history

The table below records major changes to this document

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| --- | --- |
| **Date** | **Comment** |
| 2016-11-16 | Initial |
|  |  |
|  |  |

# Audiences

## Basic knowledge requirements

Audiences are not expected to be professionals to the below terminologies, but it is expected that all of audiences should have general knowledge about them:

* Client and server communication architecture
* Persistent message queue architecture
* Online message publish-subscribe architecture
* Request load balancing and routing
* HTTP and web socket protocols
* Socket, latency, throughput and network bandwidth
* Synchronous (blocking) and asynchronous (non-blocking) communication
* TCP/IP protocol for plain text communication
* SSL/TLSv1 encryption, decryption and server authentication
* Message replication
* C API functions and interfaces
* Adapters

## Audiences

* Software architect
* Software developer
* Software development manager

# Introduction and goals

Your applications have to deal with data movement among networked computers under most cases. High development simplicity, rich feature, high availability, secure, great performance and unlimited scalability are major qualities to be considered and wished. Originally inspired by Microsoft old communication technology DCOM, long time ago UDAParts began exploring raw TCP/IP socket APIs and tried to use both blocking and non-blocking sockets for better performance as shown at the site <http://www.codeproject.com/Articles/1785/Offset-weaknesses-of-DCOM-with-strong-points-of-so>. For a long time of many trials and failures, UDParts has finally created a powerful communication framework on non-block TCP/IP socket, which is named as SocketPro.

SocketPro is created with the following goals in mind:

* Taking advantages of full-duplex network concurrency transferring by use of non-blocking TCP/IP socket
* Industrial standard SSL3/TLSv1.x for secure communication
* Inline request/result data batching for better network efficiency
* One complete and integrated solution supporting multiple communication patterns such as client/server, publish/subscribe, asynchronous durable message queue and load balancing
* Cross operation systems supported
* Great compatibility among different development languages and platforms
* Super performance and scalability
* New async development features such as Lambda expression, anonymous callback, async/await and future fully supported for various development languages
* Parallel data transferring and computation
* Guaranteed thread safety for core components and adapters
* High reusability
* Simple development
* Low coupling and high maintainability

# SocketPro data transferring pattern

SocketPro framework is created on non-blocking TCP/IP socket communication to support concurrently transferring data between two end points for the best network efficiency and concurrency by continuous inline data batching at both client and server sides simultaneously. To help you understand SocketPro data transferring pattern more clearly, please pay close attention to the below Figure 1 with your careful analyses which leads you to understand the power of SocketPro.



Figure 1: Two data transferring patterns on one socket connection

## 4.1 One-request for one-response or result

The above picture shows two types of data transferring patterns in pair for better comparison. First of all, let’s have a close look at the left one with one socket connection. It really represents a typical synchronous communication pattern by use of blocking TCP/IP socket, which is widely used by most of distributed application systems.

It is noted that many applications may use a worker thread at client side to send a request and wait for its corresponding result from a server to fake an asynchronous communication. However, it is not considered by UDAParts as a true asynchronous one because the communication pattern is just a typical pattern of one-request for one-result. Therefore, UDAParts thinks this fake asynchronous communication is still a synchronous one, whose communication pattern is actually the above left one. In comparison to the above first scenario, this one does not block this calling thread as it is freed by a worker thread although the approach has flaws of extra thread context switches and worker thread manipulations. The two scenarios are very popular as they are easy to be understood and implemented by all software engineers, architectures and project managers.

Currently a small portion of distributed application systems does use non-blocking TCP/IP sockets without use of any worker thread for asynchronous communications. However, most of them still follow one-request for one-result for processing. Each of many requests is one-by-one sent from client, processed at server side, and finally returned from server to client with an expected result. In comparison to the above two scenarios, this approach has two advantages, no calling thread blocking and no expensive thread-context switch. However, it still follows the pattern of one-request for one-result.

All the above scenarios have three fundamental issues, high latency, low network efficiency and lack of concurrency in client requests sending and processing. First of all, LAN (local area network) has a typical latency between 0.1 and 0.4 millisecond. In other words, one TCP/IP socket will never exceed 10,000 or 2,500 requests per second no matter either 1 or 10 GB switches are used with how small requests. Further, most of requests and their corresponding results are smaller than 1460 in bytes, which leads to huge waste of network bandwidth. Assuming the above assumptions are correct and each of requests has a size of 1460 bytes (note that requests could be around a few bytes in reality under many situations), each of sockets will not have a throughput of 14,600,000 (efficiency = 12% (14.6/120 megabytes) 1 GB switches) or 3,650,000 (efficiency = 0.3% (= 3.65/1200 megabytes) for 10 GB switches) bytes per second. You can see this pattern has extremely low network efficiency from view of a single socket. To solve the low network efficiency, it is very common to open multiple sockets for improving it with a huge amount of software engineering effort and cost. The second factor influencing efficiency or throughput is request data size. Obviously, the efficiency or throughput would be very bad if your application has to support high volume of small requests having a few bytes. Therefore, very few modern communication frameworks such as Apache Kafka, Apache Spark and Apache Storm employ batching multiple requests at client side and send them in one shot at a predefine time interval before putting a bigger chunk into a TCP/IP socket. It is not practical to improve network efficiency by use of better hardware having lower latency between two end points. If your application has to support WAN (wide area network) or wireless LAN, the situation could become much worse as latency could be easily between 2 and 250 milliseconds or more.

If we consider a data transferring path, it is not difficult for us to find another flaw that devices on the whole path cannot run concurrently at any time on one TCP/IP socket. This is actually a concurrency issue as it also degrades the total performance of a distributed application system significantly.

As the above fundamental issues are deeply understood by UDAParts, UDAParts has spent a long time to overcome them completely with a much more powerful communication pattern. Please keep on reading and thinking the right side communication pattern of the above figure 1.

## 4.2 Multiple-requests for multiple-responses or results

SocketPro framework is created solely on non-blocking TCP/IP socket communication to reduce the influence of high network latency on network efficiency or throughput by an in-line data batching algorithm on the fly so that all devices on a socket communication path run concurrently as long as multiple requests are available. Both client and server ends are able to push bigger data packed across multiple requests/results with inline data batching algorithm onto the other side concurrently and simultaneously.

Assuming we send n requests one-by-one with different sizes of bytes from a client to a server (see the right side of the above figure 1), the server will process one request after another sequentially once a request arrive. Since sending requests in memory is usually faster than network data transferring, an in-line data batching algorithm works silently to pack different sizes of request data into one bigger chunk before being put on network wire. This improves network efficiency or throughput due to bigger chunk data. Besides, it also reduces degradation of high networking latency on throughput. SocketPro server side does real-time stream processing since we can think SocketPro takes requests from a client as a request stream to requests just like a binary stream to bytes.

Similarly, a SocketPro server returns different sizes of results to a client by pushing style with inline data batching algorithm. Certainly, a SocketPro server is also able to emit best throughput from server to client. Under many cases, m results, which is larger than the number of requests n, will be pushed onto a client on one single socket concurrently while a client is sending requests. By this time, the number m of responses or results is either equal to or larger than the number n of requests (see the right side of the above figure 1) with SocketPro. Under some situations, the value m could be far larger than the value n. Assuming we need to download a big file from server to client, the server could push one result of a file attribute containing error code, file availability and size, a number (j) of results of file chunks, and one result of ending notification at the end. The number of request is just one, but the number of results or responses would be 1 + j + 1 totally. Apparently, this case would also happen with pushing any types of large collections such as data table and structure.

At this writing time, SocketPro data transferring pattern is unique. As far as we know, there is no other distributed application employing this or similar pattern. UDAParts has spent a considerable amount of effort to study other popular frameworks, libraries or distributed applications. UDAParts has not found any one has better throughput than SocketPro. Under most cases, SocketPro provides much better throughput under a set of same hardware and operation system. Now, let’s talk about latency. As mentioned at the above section, Apache Kafka batches multiple requests at client side and sends them in one shot at a predefine time interval before putting a bigger chunk into a TCP/IP socket. Kafka does so for better throughput, but it sacrifices the latency as a predefine time interval, which is usually a few milliseconds up to seconds so that a user has to balance between throughput and latency, which is not fun at all. Contrarily, SocketPro’s latency would be in the range of 0.x up to a few milliseconds which is dependent on hardware and request size in bytes. Note that SocketPro also provides persistent message queue functionality as Kafka does, but a SocketPro user doesn’t have to balance between throughput and latency at all. UDAParts internal studies have shown that SocketPro persistent message queue is much better than Kafka in both throughput and latency.

Due to the SocketPro unique communication pattern having inline data batching algorithm, you can easily create highly reusable thick/fat client applications on SocketPro without much degradation of application performance as a thick client has to provide more flexibility having chatter and richer functions.

Summarily, SocketPro is a world-leading package of secured communication software components written with continuous inline request/result batching, real-time stream processing and asynchronous data transferring in mind. UDAParts performance studies show that SocketPro is very easily able to saturate one 1-GB or less network bandwidth for typical power computers. SocketPro really runs nicely on 10-GB network bandwidth with powerful computer systems.

## 4.3 Multiple-requests for less-responses or results

This pattern cold be found on user own defined protocols with some applications using non-blocking TCP/IP socket. It is not difficult to create such pattern communication components, which have more number of requests than the number of returned results. This type of systems typically focuses on better request throughput but ignores on result throughput. Contrarily, SocketPro takes care of both request and result throughputs equally. Usually, this type of systems provides much simpler and less functionalities than SocketPro. Therefore, we stop here and don’t spend more effort to describe or compare it with SocketPro any more as they are not really reusable to us.

# SocketPro communication architecture

Similar to all other communication frameworks, SocketPro is designed with its own design goals as shown the below Figure 2. SocketPro framework has one client core library (usocket) and one server core library (uservercore). Both of them, which export a number of operation system C functions, are written by use of C/C++ for the best performance. You can find these C functions at the files uclient.h and userver.h, respectively. Currently, both core libraries are available for window ce, window and various Linux variant platforms.



Figure 2: SocketPro communication architecture on one socket connection

Since these system C functions are not so friendly to be used by you, UDAParts has already created a set of adapters on development languages to make you development easier. Therefore, typically your client and server codes will directly communicate only with one of adapters in middle at both client and server side. Note that your client and server could use different adapters, which are all compatible across both development languages and operation systems.

## Client core library (usocket)

As described at the above section, all of basic features of one socket connection are implemented within SocketPro client core library (usocket.dll for windows and libusocket.so for Linux platforms) as shown at the below Figure 3. One single socket connection supports online message bus for publish-subscribe communication pattern and two sets (base and user-defined) of requests within client side.

Additionally, SocketPro client library has implemented inline data compression (zipping) and decompression (unzipping) and persistent message queue (request log or backup). The first feature can be a convenient tool for you to improve data transferring performance on WAN having low bandwidth, but it is not recommended for you to use it on LAN as it requires too much CPU especially for data compression on LAN. The second feature is implemented to improve client side fault tolerance focused on network instability and client/server application shutdown for all types of reasons such as uncaught exceptions, software upgrade, server power-off, and so on. For example, in case a network switch is turned off, SocketPro client is able to resend requests saved in a persistent message queue automatically when the switch is turned on. The two features are optional.

Finally, SocketPro framework uses industrial standard SSL/TLS to secure communication by encryption and decryption between client and server sides. SocketPro employs SSPI (security support provider interface) channel on window platforms, and openssl on Linux platforms. Today, this is a standard feature for anyone of communication frameworks.



Figure 3: SocketPro client core built-in features on one socket connection

### 5.1.1 Base and user-defined request identification numbers

Each of requests is labeled by a unique identification number (id). When a client sends a request to a remote server, the server side is able to properly parse the request according to an obtained request id as each of requests has its own input signature of parameters. SocketPro has already defined a set of request ids (identification numbers) for a set of base and built-in requests, which are less than idReservedTwo (0x2001) defined at the file ../socketpro/include/ucomm.h.

All of user defined request ids are larger than or equal to idReservedTwo.

### 5.1.2 Online message bus

SocketPro client core has a built-in feature for you to quickly and conveniently use publish-subscribe pattern for exchanging various messages among online (or connected) clients. People may call the pattern as internet chatting, message notification, and online message bus as well as others. It is noted that UDAParts may use these terms interchangeably. A client can use the feature to send (publish) any messages onto one or different chat groups of connected clients through SocketPro server in middle. In addition, a client is able to notify another client identified by a targeted client login user id.

### 5.1.3 Compression and decompression

Compression is very CPU extensive. Therefore, it is not recommended for LAN in general. However, you may use the SocketPro convenient feature to reduce data transferring size for better performance if your system has to support WAN or wireless LAN. SocketPro has two compression levels, best speed and best compression. The first one is focused on compression speed with less CPU cost and compression rate, but the second one is focused on better compression rate with much lower compression speed and higher CPU cost.

### 5.1.4 Persistent message queue at client side

As described previously, this SocketPro feature is to improve client side fault tolerance. A reliable distributed application system must be designed to tolerate various faults as many as possible. However, it is not easy to solve these issues under many situations. Besides, solving these issues may make distributed application code very messy. Common faults are net wire unplug, switch power-off, software component upgrade, uncaught exception and computer power-off. In case anyone of faults happens, SocketPro is automatically able to resend the request from persistent message queue saved previously once the issue is removed. As you can see, SocketPro client persistent message queue can thought as request log for request backup.

### SocketPro pool for parallel computation

So far we have just elaborated client data transferring fundamentals, which is focused on one non-blocking socket only. In fact, a client is always required to obtain a socket from a socket pool before sending any request. A socket pool is made of one or more worker threads, and each of them hosts one or more non-blocking sockets as shown at the following Figure 4.



Figure 4: A socket pool having three worker threads for parallel computation

SocketPool is designed for transferring data from a client to one or more SocketPro servers for parallel processing. In case a client may have to process returning results with expensive CPU costs, the client should start a pool with multiple threads. For example, a high performance web server application has to deliver a considerable large record set of data onto browsers from backend database table, which may require high CPU costs concurrently on multiple cores at web server application side to process encrypted binary results as fast as possible from a SocketPro server. Under many cases, one worker thread may be enough if processing response results does not require much CPU cost.

### WaitAll for converting asynchronous requests into synchronous ones

All of sockets are always running with non-blocking communication style so that all of requests are always executed asynchronously. However, most of software developers are not used to write asynchronous codes although some development languages and libraries are gradually starting to support it. Additionally, asynchronous codes are still more complex to read usually, even though we have closure, lambda expression and anonymous delegate for help. To reduce the complexity of asynchronous codes, SocketPro client core library provides one particular function WaitAll to convert asynchronous requests into synchronous one from your code so that your code complexity may be reduced for better readability.

## Server core library (uservercore)

It is time to focus discussing key features supported at server side, which are implemented within server core library uservercore. Similar to client side, server core library also uses in-line continuous data batching algorithm on non-blocking sockets to silently pack real-time stream processing results for best network efficiency. Server core built-in features are shown at the below Figure 5.



Figure 5: SocketPro server core built-in features

SocketPro server core uses one listening socket or one port to support unlimited number of services such as HTTP/websocket, file, database access, server side persistent message queue and other user defined services. Each of them represents a group of requests. There are two built-in services, HTTP/websocket and notification (or online message bus). In addition, SocketPro server core has a built-in feature Routing implemented for load balancing. Like client core, server core supports industrial standard SSL3/TLSv1.x for secure communication, zipping/unzipping for reducing data transferring size on low bandwidth network, and server side persistent message queue. Note that the three features are optional.

### 5.2.1 Base and user requests processing

As described at the above Section 5.1.1, SocketPro server core must be able to process both base and user defined requests from clients. SocketPro processes all base requests internally without your code at all. It is reminded that all base requests have identification numbers that are less than idReservedTwo (0x2001) defined at the file ../socketpro/include/ucomm.h. On the other hand, all user requests, which always have identification numbers no less than the value idReservedTwo, are processed from your code. Besides, your code must return one or more results for each of user requests.

### 5.2.2 Online message bus and built-in service Notification

Like client core, server core has a built-in feature Notification implemented for you to quickly and conveniently use publish-subscribe pattern for exchanging various messages among online (or connected) clients from serve r side. You can use the feature to send (publish) any messages onto one or different chat or topic groups of connected clients from SocketPro server side. In addition, you are able to notify messages onto a client identified by its client login user id.

### 5.2.3 Compression and decompression

Similar to client core, SocketPro server core has this feature implemented for your convenience in case you like to reduce sending response result data size on low bandwidth network environment. Since compression is usually very CPU extensive, it is not recommended for LAN in general. At server side, SocketPro also supports two compression levels, best speed and best compression. The first one is focused on compression speed with less CPU cost, but the second one is focused on better compression rate with much higher CPU cost.

### 5.2.4 Sharable persistent message queue

Currently there are a lot of persistent message queue frameworks available, which save messages at server side only. However, SocketPro offers you persistent message queues at both client and server sides. Client persistent message queue is implemented for better fault tolerance as described at the Section 5.1.4, and server persistent queue for asynchronously offline consuming and processing with decoupled fashion. You can start any number of persistent message queues within one server application. Further, you can not only save messages from multiple providers or clients into each of these queues, but also make each of these queues de-queued by any number of consumers or clients simultaneously. Therefore, each of these queues is sharable at SocketPro server among providers and consumers. Finally, it is note that SocketPro persistent queue follows the rule of first-in-first-out.

### HTTP/websocket built-in service

SocketPro server code supports both HTTP and websocket protocols. Therefore, you can access a SocketPro server from web browsers by use of SocketPro javascript adapter if this service is enabled.

### Routing/load balancing and alpha requests

SocketPro server core has a special feature named as routing, which functions like load balancer or network device switch. As shown in the Figure 6, a large number of various requests from a set of clients can be routed onto a new set of clients or computers for processing in load balancing or parallel style.



Figure 6: SocketPro server core routing/load balancing feature

Under many cases, you may like some of client requests should be directly processed at server side instead of routed clients. These requests are called as **alpha** requests.

SocketPro routing/load balancing feature supports **sticky sessions** by either transaction queue or manual request batching at client side. Therefore, you could use the two approaches to force a set of requests processed at one client together.

SocketPro routing/load balancing feature also supports **auto fault recovery** by client persistent message queue for any errors which are related with workers as described previously at the Section 5.1.4. In case a failure happens with anyone of workers, both client and SocketPro servers are able to detect it. Automatically, failed requests could be resent and re-routed onto new workers for processing from client request persistent queue.

Finally, SocketPro routing/load balancing supports **three algorithms, default, random and average** for scheduling which one of workers to send a request to. If you use algorithm average, SocketPro will simply routes requests onto different workers in average on the number of client requests. If you use algorithm random, SocketPro scheduling is internally based on session data transferring speed between SocketPro server and worker. The last algorithm, default, is actually the combination of the two algorithms, random and average.

One particular issue you must pay attention is that all response results are not returned sequentially from different workers. However, you can embed an index for each of requests and force all of workers to always return results containing such an index. Later, you can sort results according to the index.

As you can see, SocketPro routing/load balancing feature can be a simple but powerful server tool for you to easily improve your application system horizontal scalability.

### User defined server services written from various development languages

In addition to SocketPro built-in services as described at the Sections 5.2.2 and 5.2.5, you are able to create your own services from your development languages with help of their adapters. At the moment, you could create your own server services with C/C++, .NET C#/VB.NET, Java and Python languages. Note that each of services must be registered with a unique identification number right before listening on port. A client must ask for a service based on its unique identification number before sending any other requests.

A SocketPro server can be registered with any number of services. Each of services will always support all of base requests and online message bus or notification requests by inheritance.

Service requests are classified into two categories, fast and slow requests. Fast requests are always processed within one or more pre-started threads. However, slow requests are dispatched onto worker threads for processing at run time. These worker threads are created at run time, and they are automatically killed when they are idle for a pre-defined time period. This design is created for reducing expensive thread context switches if there are lots of fast requests from client.

### Plugins written from C/C++

SocketPro supports server side plugin development. A SocketPro server plugin is actually a system standard dynamic library, which must have one or more user defined services implemented with exposing the following required seven functions at least. When a SocketPro server loads a plugin, it will use the below required functions to dispatch client requests onto your plugin for processing.

* bool WINAPI InitServerLibrary (int param); //The method will be called from SocketPro server core right after the library is loaded
* void WINAPI UninitServerLibrary(); //The method will be called from SocketPro server core right before the library is going to be unloaded
* unsigned short WINAPI GetNumOfServices(); //SocketPro will use the method to query how many services the library has defined
* unsigned int WINAPI GetAServiceID(unsigned short index); //The method will be called from SocketPro server core to query each service id on zero-based index
* CSvsContext WINAPI GetOneSvsContext(unsigned int serviceId); //The method will be called from SocketPro server core to get service context for a given service id
* unsigned short WINAPI GetNumOfSlowRequests(unsigned int serviceId); //The method will be called from SocketPro server core to query the number of slow requests for one service id
* unsigned short WINAPI GetOneSlowRequestID(unsigned int serviceId, unsigned short index); //The method will be called from SocketPro server core to get a slow request id from given service id and zero-based index

Currently, you can only create SocketPro server plugins from C/C++.

## Replication of one queue of messages to others

As described at the above two sections 5.1 and 5.2, both client and server sides support persistent message queue. SocketPro client queue is used for request backup so that a request can be resent to server in case there is any error such as network failure, server application shutdown and power-off. SocketPro server queue, like other typical queues, provides an asynchronous communication between publishers and subscribers which do not need to interact with message queue at the same time. Further, SocketPro is also able to replicate one queue of messages onto others as shown in the below Figure 7 at both client and server sides.



Figure 7: One source queue of messages replicated onto three target queues with transaction style

It is noted that SocketPro queue replication is fully in agreement of all ACID (atomicity, consistency, isolation and durability) properties, and guarantees complete consistency or the exactly same data among all replicated copies.

# Tutorials for beginners

## Must-have requirements

* Both client and server libraries must support the communication protocol as described at the sections 5.1 through 5.4.
* Client library must expose a function in some ways to verify certificate sourced from server side before sending any sensitive data. There is no certificate verification at server side at this writing time.
* SSL/TLSv1 version 3.0 or higher is required for both client and server libraries.

## Optional but highly recommended features

* Three communication events, SSL handshake done, data arrive, and session disconnection.
* Non-blocking communication with full support on blocking request at higher level by calling the method like WaitAll at client side.
* Expose session state information such as error code, error message, session connection state and endian-difference as well as others.
* PostClose or Close method at client, server or both sides to close a communication session.
* Both client and server libraries should have dependencies as low as possible.
* Both client and server libraries should be highly reusable friendly within multi-threading environments.
* Auto session reconnection after disconnection.
* Session connecting timeout at client side.
* Both client and server libraries should be converted onto other development environments (for example, .NET).
* Request or command receiving timeout at client side.

## Technologies used for windows implementation

* Meet all requirements listed at the section 4.1.
* Visual C++ will be used for windows environment development tool.
* C++11 new features.
* Openssl libraries for SSL/TLSv1 encryption and description.
* BOOST ASIO communication framework.
* Window socket 32-bit and 64-bit system libraries.
* Both client and server libraries are standard system libraries exposing C structures and functions as well as interfaces only. No classes are permitted to be exposed from the standard system libraries, although implementations at client and server libraries may heavily use C++ classes and C++ 11 new features as well as other advanced features internally.
* All optional features listed in the section 4.2, except the last one, are implemented for window platforms.
* Other minor features.

## Technologies used for non-windows implementation

* Must meet all the basic requirements as listed at the section 4.2.
* Open to any acceptable development environments and tools as well as frameworks
* Open to any acceptable SSL/TLSv1 supported libraries, but Openssl libraries are highly recommended.
* Features listed at the above section 4.3 are highly recommended, although these features are not must-have ones.

# Development of plugins

## Internal communication protocol

### 5.1.1 Request or command structure

Whenever a client sends a request (command), we could use the following eight-byte structure to clearly describe it. We could also use the exactly same structure to describe returning result from server side.

*#pragma pack(push,1)*

*typedef struct CRequestHeader {*

*CRequestHeader()*

*: RequestId(0),*

*Reserved(0),*

*Size(0) {*

*}*

*void Reset() {*

*RequestId = 0;*

*Reserved = 0;*

*Size = 0;*

*}*

*unsigned short RequestId; //A request identification number, which can* ***NOT*** *be zero*

*unsigned short Reserved; //Reserved for the future use (online compression and decompression)*

*unsigned int Size; //Request chunk data size in bytes*

*} RequestHeader;*

*#pragma pack(pop)*

We could use the request id to identify what request is at server side and what result is at client side. The member Reserved is reserved and always set to zero at the moment. We may use it to support online compression and decompression in the future to accelerate file or database record set transferring between client and server with low bandwidth network. The last member Size is used to indicate the size of request data chunk in bytes. As you can see, we could always retrieve the first eight bytes of data for the structure first. Afterwards, we could always retrieve the coming request or result data chunk from the structure member Size at both client and server sides.

Note that request id can NOT be zero. Therefore, the implementation of both client and server libraries should ensure there is no request transferred with request id equal to zero between client and server.

### 5.1.2 Reserved request Ids

To make the protocol work correctly, we also reserved the following four predefined request ids for different purposes:

*static const unsigned short idAuthentication = 1;*

*static const unsigned short idServerException = 2;*

*static const unsigned short idHeartBeat = 3;*

*static const unsigned short idAuthenticationReserved = 256;*

* 1. idAuthentication and idAuthenticationReserved

The id *idAuthentication* is used to ensure that a client must always send the client credentials to server before sending any other requests right after both TCP/ICP and SSL/TLSv1 handshakes are completed. This rule is set for better security purpose

The second id *idAuthenticationReserved* is used to detect endian difference between client and server. When a client sends an authentication request to a server, if the server gets this reserved id instead of *idAuthentication*, we are ensured that the client and server have different endians at server side. Similarly, the client will know that its endian is different from its server endian right after seeing returning authentication result. Note that we may not meet endian-difference situation in the near future, but we consider it ahead. Also, both client and server libraries ensure there is no possibility to send this particular request from other software components. Otherwise, libraries will be confused with endian-difference.

* 1. idServerException

This id is used to transfer the following data from server to client in the following predefined order:

* A two-byte unsigned short for current request id
* A four-byte integer for anyone of error codes
* An ASCII string with a four-byte integer length indicator ahead for error message
* An ASCII string with a four-byte integer length indicator ahead for stack

Therefore, you could use the above information as a base to build error logging file for runtime debugging at client, server or both sides.

* 1. idHeartBeat

This id is used to detect abnormal session disconnection. At client side, client library should always send an empty request having this request id with zero size at a predefine interval (TBD), whenever there is no data transaction between client and server during the interval period. Server library will use this logic to detect abnormal client detection if there is no data received during the predefined interval period. Similarly, client library is able to do the same detection.

Note that both client and server are able to detect normal session disconnection at real time fashion, which is highly preferred, although this is not required for both client and server libraries.

## Windows implementation approach

From now on until the end of this document, it is focused on windows communication implementation only, which is realized from asynchronous communication style with help of boost asio framework for easy and fast development. In regards to other platforms, other implementations may refer to the windows platform implementation, but do not have to follow this implementation exactly as long as they abide by the rules defined at sections 4.1 and 5.1 through 5.4.

It is highly recommended that you should read through the following two boost ASIO doc sites:

* [*http://www.boost.org/doc/libs/1\_55\_0/doc/html/boost\_asio/overview/core/basics.html*](http://www.boost.org/doc/libs/1_55_0/doc/html/boost_asio/overview/core/basics.html)
* [*http://www.boost.org/doc/libs/1\_55\_0/doc/html/boost\_asio/overview/core/async.html*](http://www.boost.org/doc/libs/1_55_0/doc/html/boost_asio/overview/core/async.html)

# Performance studies

All defined constancies, structures and interfaces in this section are declared at the file sccomm.h. They are shared by both client and server core libraries.

## Error codes

There are a few defined constancies with comments, as described at the following.

*//error codes for the method Retrieve of interface ISession*

*//and the method Send of interfaces IClientSession and IServerSession*

*//as well as the method SendException of interface IServerSession*

*static const unsigned int SESSION\_CLOSED = (~0); //session closed*

*static const unsigned int BAD\_REQUEST = SESSION\_CLOSED - 1; //Unexpected request id at client side*

*static const unsigned int BAD\_RETRIEVE\_THREAD = BAD\_REQUEST - 1; //Retrieve data from wrong thread*

*static const unsigned int BAD\_RESULT = BAD\_REQUEST; //Send result with wrong request id*

They are used with the methods *Retrieve* and *Send* as well as *SendException*.

## Session states

There are a few defined session states as described at the following. These sessions are obvious to everyone.

*typedef enum tagSessionState {*

*ssClosed = 0,*

*ssClosing = 1,*

*ssConnecting = 2,*

*ssConnected = 3,*

*ssSslHandshaking = 4,*

*ssSslHandshaked = 5,*

*ssAuthentcated = 6*

*} SessionState;*

Note that session state would be at the session state *ssAuthenticated* after a client request *idAuthentication* is sent and processed.

## Interface ISession

We define a basic interface with a number of methods shared between client and server sides. Its major methods are listed as the below with ignoring obvious ones.

*struct ISession {*

*//Check the data size in bytes to be sent to remote peer.*

*//If it returns a large vaule, it means network bandwidth is not matchable for sending speed*

*virtual unsigned int GetSendingBufferSize() = 0;*

*//Set a buffer recv with length size in bytes to receive error message terminated by null*

*virtual unsigned int GetErrMsg(char \*recv, unsigned int size) = 0;*

*//Set a buffer recv with length size in bytes to receive data*

*//Must call this method within the thread hosting boost asio io service object*

*//The method returns the actually obtained data length or BAD\_RETRIEVE\_THREAD*

*virtual unsigned int Retrieve(unsigned char \*recv, unsigned int size) = 0;*

*};*

Both client and server libraries implements the interface to support reusing it within multi-threading friendly and easily. Note that we may add new methods into the interface without breaking code compatibility.

## Interface ICertificate

We also define an interface to access SSL/TLSv1 certificate for its verification before sending any sensitive data. Note that we may add new methods into the interface without breaking code compatibility.

Its major methods are listed as the below with ignoring obvious ones.

*struct ICertificate {*

*virtual const char\* const Verify(int \*errCode) = 0;*

*virtual const char\* const GetCertPem() = 0;*

*virtual const char\* const GetSessionInfo() = 0;*

*virtual bool IsValid() = 0;*

*virtual const char\* const GetSubject() = 0;*

*virtual const char\* const GetIssuer() = 0;*

*virtual const unsigned char\* const GetPublicKey(unsigned int \*pKeySize) = 0;*

*};*

Note that we have implemented the interface at client side as required at the section 4.1, but not at server side.

## Callback definitions

We also define the following four obvious callbacks to track session events shared by both client and server libraries. Note the namespace SC stands for secured communication just for your information.

*typedef void (CALLBACK \*POnArrive) (SC::ISession \*session, unsigned short RequestId, unsigned int Size);*

*typedef void (CALLBACK \*POnClose) (SC::ISession \*session);*

*typedef void (CALLBACK \*POnLess) (SC::ISession \*session);*

*typedef void (CALLBACK \*POnSslHandshakeDone) (SC::ISession \*session);*

## Session callback structure

At last, we define a structure which will be passed into both client and server core libraries so that its callback functions, which are actually implemented from a calling library, could be correctly called at a proper time.

*struct SessionCallback {*

*//!!!! must initialize the following callbacks*

*POnSslHandshakeDone OnSslHandshakeDone; //SSL handshake done event*

*POnArrive OnArrive; //command or result arrive event*

*POnClose OnClose; //session disconnection event*

*POnLess OnLess; //sending buffer no data event*

*};*

# Event notifications

## Goals

The server library is a window standard system library with exposing three C functions at this writing time. A server is able to accept and support multiple sessions and make sure these sessions run concurrently without blocking each other from client view. The server library is able to be easily reused from .NET environment.

## Achievements

The server library is created to replace the classes *CListensoc* (*CListen60soc*) and *CConectSoc* of existing project *UcsdServer*. The future class *CListenServer* will not be derived from the *MFC* class *CWinThread*. We’ll totally get rid of *MFC* from both client and server libraries.

## Interface IServerSession and one callback

In addition to the interface ISession, we also define a new interface IServerSession from the interface ISession for specific session methods of server side.

*struct IServerSession : public ISession {*

*//Send a result chunk buffer with length size onto remote client for a request ReqId*

*//It returns the actually length data, SESSION\_CLOSED, or BAD\_RESULT*

*virtual unsigned int Send(unsigned short ReqId, const unsigned char \* const buffer, unsigned int size) = 0;*

*//Send an exception (ec, msg and stack) onto remote client for current request CurReqtId*

*//It returns the actually length data in bytes, SESSION\_CLOSED, or BAD\_RESULT*

*virtual unsigned int SendException(unsigned short CurrReqId, int ec, const char \*msg, const char \*stack) = 0;*

*//Tell the underlying server core library that we are going to use a worker thread for processing*

*//Must call this method within main thread before starting a worker thread. Otherwise, it returns false.*

*virtual bool StartThreadProcessing() = 0;*

*//Tell the underlying server core library that worker thread for processing is completed*

*//Must call this method from a worker thread. Otherwise, it returns false or no processing for this session.*

*virtual bool EndThreadProcessing() = 0;*

*};*

The following callback is called by listening socket when a socket session is initialized at server side. Server side will return a structure for four callbacks, which are implemented from a calling server library or application, so that server will use the four callbacks to notify events at proper times. By the same time, a calling library or application will record an IServerSession interface to access session at server side.

*typedef SC::SessionCallback (CALLBACK \*POnAccepted)(SC::ServerSide::IServerSession \*session);*

## Three C functions

At this writing time, the server library only exposes the following three C functions.

const char\* WINAPI InitializeSecureCommServer(POnAccepted OnAccepted, unsigned int port = 22260, bool v6 = false, unsigned int backlog = 16);

const char\* WINAPI RunSecureCommServer(const char \*certFile, const char \*keyFile, const char \*pwdForPrivateKeyFile, const char \*dhFile = nullptr);

void WINAPI ShutdownSecureCommServer();

The first two functions will return an error message if available.

In short, we need to call the first method *InitializeSecureCommServer* with a callback *OnAccepted* that is implemented within either calling library or application. Afterwards, we call the method *RunSecureCommServer* with SSL-related files to start the secure socket server. When a client establishes a socket connection, the callback *OnAccepted* will be called from the server library. Referring to the definition *POnAccepted* at the section 7.3, you can get an interface *IServerSession* to the newly established session. In addition, you have to return a structure for session callbacks that are implemented within calling library or server application. Internally, the server library will call your codes through the callback structure at proper times.

As expected at the end, call the method *ShutdownSecureCommServer* to kill the internal listening socket and its associated sessions if available.

# Other examples

## Goals

The client library is also a window standard system library with exposing three C functions at this writing. The client library also implements a number of callbacks to notify common socket session events to any calling 32-bit and 64-bit libraries or application. Also, the client library is able to be easily reused from .NET environment to take advantage of .NET new key words async and await.

## Achievements

The client library is created to replace the *MFC* class *CSocket*. Like server library, we don’t use *MFC* within the new client library at all.

## Interface IClientSession

Similar to the server interface *IServerSession*, we derive a new interface IClientSession from the base interface ISession for specific methods of client session as described at the following.

*struct IClientSession : public ISession {*

*//Wait until all queued requests are processed, timeout or session closed.*

*//The method returns true only if all queued requests are processed.*

*virtual bool WaitAll(unsigned int ms) = 0;*

*//Send a data chunk buffer with length size onto remote server for a request RequestId*

*//it returns the actually length data, SESSION\_CLOSED, or BAD\_REQUEST*

*virtual unsigned int Send(unsigned short RequestId, const unsigned char \* const buffer, unsigned int size, bool oneWay) = 0;*

*virtual bool IsAutoConnecting() = 0;*

*virtual size\_t GetRequestCountQueued() = 0;*

*virtual ICertificate\* GetCertificate() = 0;*

*};*

The interface is defined with detailed comments for key methods. The method *WaitAll* is used to easy convert asynchronous requests into synchronous if proper for simplifying code logic.

If you set the last input parameter *oneWay* to true for the method *Send*, this request will be one way and ignored at client side if you call the method *WaitAll*.

The method *IsAutoConnecting* is defined here to support auto reconnection.

## Three C functions

Client core library just exposes three C functions only as listed at the below.

*//certificate verification*

*int WINAPI SetCertificateVerifyFile(const char \*caFile);*

*//manage socket life*

*SC::ClientSide::IClientSession\* WINAPI DoClientConnection(SC::SessionCallback sc, const char \*host, unsigned int port, unsigned int timedout, bool autoConnecting, bool v6);*

*void WINAPI DestroyClient(SC::ClientSide::IClientSession \*session);*

The first function is used to set CA (Certificate Authority) certificate file path for certificate verification at client side. The last two functions are used to manage socket session life. When you make a call *DoClientConnection*, you get an interface *IClientSession* after you set a structure for four callbacks that are implemented at calling libraries or application. The other parameters are obvious. When the session is no longer needed, we simply call the method *DestroyClient* to kill it.

# Other examples

## Purposes

After reading through the sections 7.4 and 8.4, you may get ideas how the two core libraries work in general. However, you may still have some difficulties to use the two core libraries as we implement the two standard window system libraries exposing C functions. To reduce these difficulties, we create adapters to make reusing the two libraries easier.

Note the adapters don’t belong to the core communication libraries at all.

## Server adapter and client unit test code snippet

Here is a sample test code snippet for server side:

*int \_tmain(int argc, \_TCHAR\* argv[]) {*

*string errMsg = InitializeSecureCommServer(CServerHandlerBase::OnAccepted<CRequestHandler>, 20901);*

*if (!errMsg.size())*

*errMsg = ::RunSecureCommServer("server.pem", "server.pem", "test", "dh512.pem");*

*if (errMsg.size())*

*cout << "Error message = " << errMsg <<endl;*

*cout << "Press any key to shutdown the application ......" << endl;*

*getchar();*

*ShutdownSecureCommServer();*

*return 0;*

*}*

Referring to the section 7.4, you can quickly understand these calls. The input *CServerHandlerBase::OnAccepted<CRequestHandler>* actually is a callback for *POnAccepted*. It will become very clear to you after reading through the template function and its inside comments.

## Client adapter and server unit test code snippet

Here is a sample client code snippet.

*int \_tmain(int argc, \_TCHAR\* argv[]) {*

*int errCode = ::SetCertificateVerifyFile("ca.pem");*

*//Call DoClientConnection within constructor*

*//Call DestroyClient within destructor*

*CRequestHandler handler("localhost", 20901);*

*SC::ICertificate \*cert = handler.GetCertificate();*

*if (!cert) {*

*std::cout << "No connection! error code = " << handler.GetErrCode()*

*<< ", error message = " << handler.GetErrMsg() << std::endl;*

*return 1;*

*}*

*//do ceritificate verification before sending any sensitive data*

*const char \*str = cert->Verify(&errCode);*

*std::cout << "Cert verification result = " << str*

*<< " with error code = " << errCode << std::endl;*

*std::cout << "SSL session info: " << cert->GetSessionInfo() << std::endl;*

*std::cout << "Cert perm :\r\n" << cert->GetCertPem() << std::endl;*

*//do authentication first, which is required from server side for better security*

*if (!handler.DoAuthentication("MDTUser", "SomePassword", "charliedev-1")) {*

*std::cout << "Authentication failed" << std::endl;*

*return 1;*

*}*

*//set a callback for returning result*

*SC::ClientSide::ResultHandler rh = [](SC::ClientSide::CAsyncResult &ar) {*

*std::string res;*

*ar >> res;*

*std::cout << res << std::endl;*

*};*

*unsigned int res = handler.SendRequest(idSayHelloWorld, "Philip", "Dalrymple", rh);*

*res = handler.SendRequest(idSleep, (unsigned int)5000, [](SC::ClientSide::CAsyncResult &ar){});*

*res = handler.SendRequest(idSayHelloWorld, "Bob", "Gargan", rh);*

*//bool ok = handler.WaitAll();//convert asynchronous computations into synchrnous ones*

*std::cout << "Press any key to shutdown the application ......" << std::endl;*

*::getchar();*

*return 0;*

*}*

The above code snippet demonstrates typical usage cases of client core library with help of client adapter with sending a few requests. Note you can convert all asynchronous requests into synchronous ones by calling the method *WaitAll* at your will anytime after authentication.

At last, asynchronous computation style works greatly for window .NET form application as .NET version 4.5 starts supporting key words *async* and *await* for better UI response. In regards to window C++/MFC development environment, you can use window system function PostMessage to update UI elements after a returning result arrives.