hadoop-rpc 源码分析

一 hadoop-rpc 模块

1.1 概述

Hadoop RPC 框架中的序列化机制实现有两种：
1. Avro Writable 接口实现，简单易懂
2. Google Protobuf 跨语言实现，跨语言，高扩展，高效率

Hadoop-1.x 版本使用默认实现的 Writable 协议作为 RPC 协议，而在 Hadoop-2.x 版本，重写了 RPC 框架，改成默认使用 Protobuf 协议作为 Hadoop 的默认 RPC 通信协议。 在 YARN 中， 任何两个需相互通信的组件之间仅有一个 RPC 协议，而对于任何一个 RPC 协议，通信双方有一端是 Client，另一端为 Server，且 Client 总是主动连接 Server 的，因此，YARN 实际上采用的是拉式（pull-based）通信模型

1.2 案例

1.2.1 Writable 协议

Pom 依赖

```
<dependency>
        <groupId>org.apache.hadoop</groupId>
        <artifactId>hadoop-common</artifactId>
        <version>3.1.3</version>
    </dependency>
```

协议接口

```
/**
 * 业务协议接口
 */
public interface BusinessProtocol {

    /**
     * 版本 ID
     */
    long versionID = 123456L;
```

```
    void mkdirs(String path);
    String getName(String name);
}
```

协议实现类

```
public class BusinessProtocolImpl implements BusinessProtocol {

    @Override
    public void mkdirs(String path) {
        System.out.println("server revived mkdirs request with path " + path);
    }

    @Override
    public String getName(String name) {
        System.out.println("server revived getName request");
        return "server name";
    }
}
```

Server 端

```
public class BusinessServer {
    public static void main(String[] args) {
        try {
            /**
             * 构建 rpc server
             */
            RPC.Server server = new RPC.Builder(new Configuration())
                    .setProtocol(BusinessProtocol.class)
                    .setInstance(new BusinessProtocolImpl())
                    .setBindAddress("127.0.0.1")
                    .setPort(10001)
                    .build();
            /**
             * 启动 rpc server
             */
            server.start();
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```

Client 端

```
public class BusinessClient {
    public static void main(String[] args) {
        try {
            /**
             * 获取 rpc client proxy
             */
            BusinessProtocol proxy = RPC.getProxy(
                    BusinessProtocol.class,
                    BusinessProtocol.versionID,
                    new InetSocketAddress("127.0.0.1", 10001),
                    new Configuration()
            );
            /**
             * 执行业务处理
             */
            proxy.mkdirs("/usr/root");
            String response = proxy.getName("hello-server");
            System.out.println("client revived request response with " + response);
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```

1.2.2 Protobuf 协议

备注：本地笔记本安装 protobuf

Protobuf-3.19 下载链接：

https://github.com/protocolbuffers/protobuf/releases/tag/v3.19.5

相关帖子：https://blog.csdn.net/liu644911337/article/details/128176129

Pom 依赖

```
 <dependency>
            <groupId>org.apache.hadoop</groupId>
            <artifactId>hadoop-common</artifactId>
            <version>3.1.3</version>
        </dependency>

        <dependency>
            <groupId>com.google.protobuf</groupId>
            <artifactId>protobuf-java</artifactId>
```

```
                    <version>3.19.5</version>
                </dependency>
```

ResourceTrackerMessage.proto

```
option java_package = "com.tan.hadoop.rpc.proto";
option java_outer_classname = "ResourceTrackerMessage";
option java_generic_services = true;
option java_generate_equals_and_hash = true;

message RequestProto{
    required string hostname = 1;
    required int32 cpu = 2;
    required int32 memory = 3;
}
message ResponseProto{
    required string flag = 1;
}

//        protoc.exe --java_out=./ ResourceTrackerMessage.proto
```

ResourceTracker.proto

```
option java_package = "com.tan.hadoop.rpc.proto";
option java_outer_classname = "ResourceTracker";
option java_generic_services = true;
option java_generate_equals_and_hash = true;

import "ResourceTrackerMessage.proto";

service ResourceTrackerService {
    rpc registerNodeManager(RequestProto) returns (ResponseProto);
}

// protoc.exe --java_out=./ ResourceTracker.proto
```

协议接口

```
public interface ResourceTrackerProtocol {
        ResourceTrackerMessage.ResponseProto
registerNodeManager(ResourceTrackerMessage.RequestProto request) throws Exception;
}
```

协议实现类

```
public class ResourceTrackerProtocolImpl implements ResourceTrackerProtocol {
        @Override
        public                                                  ResourceTrackerMessage.ResponseProto
```

```
registerNodeManager(ResourceTrackerMessage.RequestProto request) throws Exception {
        // 构建一个响应对象，用于返回
        ResourceTrackerMessage.ResponseProto.Builder builder =
                ResourceTrackerMessage.ResponseProto
                        .newBuilder();

        // 输出注册的消息
        String hostname = request.getHostname();
        int cpu = request.getCpu();
        int memory = request.getMemory();
        System.out.println("注册消息：  hostname = " + hostname + ", cpu = " + cpu + ",
memory = " + memory);

        // 直接暴力返回 True
        builder.setFlag("true");
        return builder.build();
    }
}
```

Proto 协议接口

```
@ProtocolInfo(protocolName = "com.tan.hadoop.rpc.proto.ResourceTrackerPB", protocolVersion
= 1)
public interface ResourceTrackerPB extends
ResourceTracker.ResourceTrackerService.BlockingInterface {
}
```

Proto 协议实现类

```
public class ResourceTrackerServerSidePB implements ResourceTrackerPB {
    final private ResourceTrackerProtocol server;
    public ResourceTrackerServerSidePB(ResourceTrackerProtocol server) {
        this.server = server;
    }
    @Override
    public ResourceTrackerMessage.ResponseProto registerNodeManager(RpcController
controller, ResourceTrackerMessage.RequestProto request) throws ServiceException {
        try {
            return server.registerNodeManager(request);
        } catch (Exception e) {
            e.printStackTrace();
        }
        return null;
    }
}
```

Server 端

```
public class ProtobufRpcServer {
    public static void main(String[] args) throws IOException {
        Configuration conf = new Configuration();
        String hostname = "localhost";
        int port = 9998;
        RPC.setProtocolEngine(conf, ResourceTrackerPB.class, ProtobufRpcEngine.class);
        // 构建 Rpc Server
        RPC.Server server = new RPC.Builder(conf)
                .setProtocol(ResourceTrackerPB.class)
                .setInstance((BlockingService) ResourceTracker.ResourceTrackerService
                        .newReflectiveBlockingService(new
ResourceTrackerServerSidePB(new ResourceTrackerProtocolImpl())))
                .setBindAddress(hostname)
                .setPort(port)
                .setNumHandlers(1)
                .setVerbose(true)
                .build();
        // Rpc Server 启动
        server.start();
    }
}
```

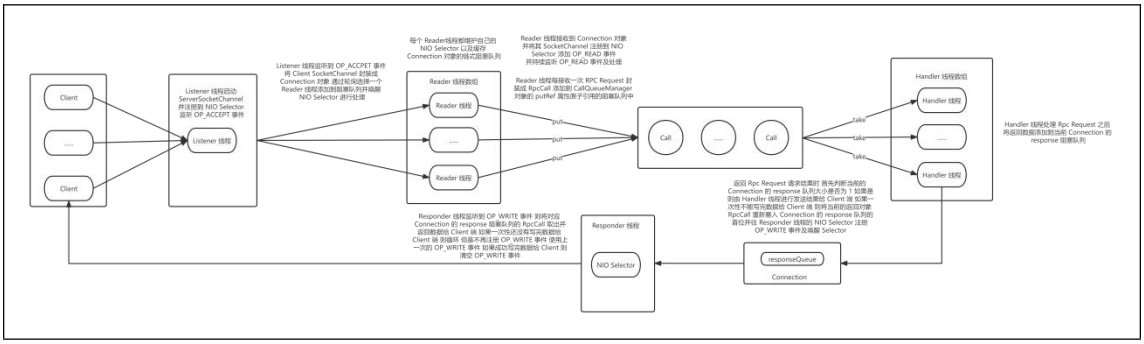
Client 端

```
public class ProtobufRpcClient {
    public static void main(String[] args) throws IOException {
        // 设置 RPC 引擎为 ProtobufRpcEngine
        Configuration conf = new Configuration();
        String hostname = "localhost";
        int port = 9998;
        RPC.setProtocolEngine(conf, ResourceTrackerPB.class, ProtobufRpcEngine.class);
        // 获取代理
        ResourceTrackerPB protocolProxy = RPC
                .getProxy(ResourceTrackerPB.class, 1, new InetSocketAddress(hostname,
port), conf);
        // 构建请求对象
        ResourceTrackerMessage.RequestProto.Builder builder =
                ResourceTrackerMessage.RequestProto
                        .newBuilder();
        ResourceTrackerMessage.RequestProto requestProto = builder
                .setHostname("hadoop")
                .setCpu(64)
                .setMemory(128)
                .build();
```

```
            // 发送 RPC 请求，获取响应
            ResourceTrackerMessage.ResponseProto response = null;
            try {
                response = protocolProxy
                        .registerNodeManager(null, requestProto);
                // 处理响应
                String flag = response.getFlag();
                System.out.println("最终注册结果：  flag = " + flag);
            } catch (ServiceException e) {
                e.printStackTrace();
            }
        }
}
```

1.3 rpc-server 源码剖析

备注：基于 Protobuf 协议探索 rpc 源码
架构图如下



1.3.0 设置协议引擎

类：org.apache.hadoop.ipc.RPC

```
RPC.setProtocolEngine(conf, ResourceTrackerPB.class, ProtobufRpcEngine.class);
----------------------------------------------------------------------------------------------------------------------------
    public static void setProtocolEngine(Configuration conf,
                                          Class<?> protocol, Class<?> engine) {
        conf.setClass(ENGINE_PROP + "." + protocol.getName(), engine, RpcEngine.class);
    }
```

1.3.1 初始化 server 配置

类：org.apache.hadoop.ipc.RPC.Builder

1.3.1.1 设置协议接口

```
/** Mandatory field */
public Builder setProtocol(Class<?> protocol) {
    this.protocol = protocol;
    return this;
}
```

1.3.1.2 设置协议实现类

```
/** Mandatory field */
public Builder setInstance(Object instance) {
    this.instance = instance;
    return this;
}
```

1.3.1.3 绑定 IP 和 PORT

```
/** Default: 0.0.0.0 */
public Builder setBindAddress(String bindAddress) {
    this.bindAddress = bindAddress;
    return this;
}

/** Default: 0 */
public Builder setPort(int port) {
    this.port = port;
    return this;
}
```

1.3.1.4 其他核心参数设置

```
/** Default: -1 */
```

```
        public Builder setnumReaders(int numReaders) {
            this.numReaders = numReaders;
            return this;
        }

        /** Default: 1 */
        public Builder setNumHandlers(int numHandlers) {
            this.numHandlers = numHandlers;
            return this;
        }

    /** Default: -1 */
        public Builder setQueueSizePerHandler(int queueSizePerHandler) {
            this.queueSizePerHandler = queueSizePerHandler;
            return this;
        }
```

1.3.2 构建 RPC.Server 对象

```
public Server build() throws IOException, HadoopIllegalArgumentException {
            if (this.conf == null) {
                throw new HadoopIllegalArgumentException("conf is not set");
            }
            if (this.protocol == null) {
                throw new HadoopIllegalArgumentException("protocol is not set");
            }
            if (this.instance == null) {
                throw new HadoopIllegalArgumentException("instance is not set");
            }
            return   // 获取协议引擎 ProtobufRpcEngine
                    getProtocolEngine(this.protocol, this.conf)
                            // 获取 RPC.Server
                    .getServer(
                            this.protocol,
                            this.instance,
                            this.bindAddress,
                            this.port,
                            this.numHandlers,
                            this.numReaders,
                            this.queueSizePerHandler,
                            this.verbose,
                            this.conf,
```

```
                                    this.secretManager,
                                    this.portRangeConfig,
                                    this.alignmentContext);
        }
    }
```

1.3.2.1 获取协议引擎 ProtobufRpcEngine

```
// return the RpcEngine configured to handle a protocol
    static synchronized RpcEngine getProtocolEngine(Class<?> protocol,
                                                    Configuration conf) {
        RpcEngine engine = PROTOCOL_ENGINES.get(protocol);
        if (engine == null) {
            Class<?> impl = conf.getClass(ENGINE_PROP + "." + protocol.getName(),
                    WritableRpcEngine.class);
            // 通过反射创建 ProtobufRpcEngine 对象
            engine = (RpcEngine) ReflectionUtils.newInstance(impl, conf);
            PROTOCOL_ENGINES.put(protocol, engine);
        }
        return engine;
    }
```

1.3.2.2 获取 RPC.Server

```
public Server(Class<?> protocolClass, Object protocolImpl,
                    Configuration conf, String bindAddress, int port, int numHandlers,
                    int numReaders, int queueSizePerHandler, boolean verbose,
                    SecretManager<? extends TokenIdentifier> secretManager,
                    String portRangeConfig, AlignmentContext alignmentContext)
                throws IOException {
            // 调用父类
            super(bindAddress, port, null, numHandlers,
                    numReaders, queueSizePerHandler, conf, classNameBase(protocolImpl
                            .getClass().getName()), secretManager, portRangeConfig);
            setAlignmentContext(alignmentContext);
            this.verbose = verbose;
            // 注册协议及其实现类
            registerProtocolAndImpl(RPC.RpcKind.RPC_PROTOCOL_BUFFER, protocolClass,
                    protocolImpl);
        }
```

1.3.2.2.1 RPC.Server 构造方法

```
protected Server(String bindAddress, int port,
                 Class<? extends Writable> rpcRequestClass, int handlerCount,
                 int numReaders, int queueSizePerHandler, Configuration conf,
                 String serverName, SecretManager<? extends TokenIdentifier>
secretManager,
                 String portRangeConfig)
        throws IOException {
    this.bindAddress = bindAddress;
    this.conf = conf;
    this.portRangeConfig = portRangeConfig;
    this.port = port;
    this.rpcRequestClass = rpcRequestClass;
    this.handlerCount = handlerCount;
    this.socketSendBufferSize = 0;
    this.serverName = serverName;
    this.auxiliaryListenerMap = null;
    // Server 端接收最大数据长度 默认值 64MB (key = ipc.maximum.data.length)
    this.maxDataLength                                                    =
conf.getInt(CommonConfigurationKeys.IPC_MAXIMUM_DATA_LENGTH,
            CommonConfigurationKeys.IPC_MAXIMUM_DATA_LENGTH_DEFAULT);
    if (queueSizePerHandler != -1) {
        this.maxQueueSize = handlerCount * queueSizePerHandler;
    } else {
        // 每个 handler 线程队列最大接收多少个 call 默认值 100 (key =
ipc.server.handler.queue.size)
        this.maxQueueSize = handlerCount * conf.getInt(
                CommonConfigurationKeys.IPC_SERVER_HANDLER_QUEUE_SIZE_KEY,

CommonConfigurationKeys.IPC_SERVER_HANDLER_QUEUE_SIZE_DEFAULT);
    }
    // Server 端返回客户端请求最大数 默认值 1024*1024 (key =
ipc.server.max.response.size)
    this.maxRespSize = conf.getInt(
            CommonConfigurationKeys.IPC_SERVER_RPC_MAX_RESPONSE_SIZE_KEY,

CommonConfigurationKeys.IPC_SERVER_RPC_MAX_RESPONSE_SIZE_DEFAULT);
    if (numReaders != -1) {
        this.readThreads = numReaders;
    } else {
        // Server 端读取 socket 线程数 默认值 1 (key =
ipc.server.read.threadpool.size)
        this.readThreads = conf.getInt(
                CommonConfigurationKeys.IPC_SERVER_RPC_READ_THREADS_KEY,
```

```
CommonConfigurationKeys.IPC_SERVER_RPC_READ_THREADS_DEFAULT);
        }
        // Server 端连接 socket 最大阻塞数 默认值 100 (key = ipc.server.read.connection-queue.size)
        this.readerPendingConnectionQueue = conf.getInt(

CommonConfigurationKeys.IPC_SERVER_RPC_READ_CONNECTION_QUEUE_SIZE_KEY,

CommonConfigurationKeys.IPC_SERVER_RPC_READ_CONNECTION_QUEUE_SIZE_DEFAULT);

        // Setup appropriate callqueue
        final String prefix = getQueueClassPrefix();
        // 创建 CallQueueManager 对象
        this.callQueue = new CallQueueManager<Call>(
                // 获取阻塞队列类型 默认值 LinkedBlockingQueue.class
                getQueueClass(prefix, conf),
                // 获取调度器 默认值 DefaultRpcScheduler.class
                getSchedulerClass(prefix, conf),
                // 默认值 false
                getClientBackoffEnable(prefix, conf),
                maxQueueSize,
                prefix,
                conf);

        this.secretManager = (SecretManager<TokenIdentifier>) secretManager;
        this.authorize =

conf.getBoolean(CommonConfigurationKeys.HADOOP_SECURITY_AUTHORIZATION,
                        false);

        // configure supported authentications
        this.enabledAuthMethods = getAuthMethods(secretManager, conf);
        this.negotiateResponse = buildNegotiateResponse(enabledAuthMethods);

        // Start the listener here and let it bind to the port
        // 创建 Listener 线程并启动 ServerSocketChannel 监听 OP_ACCEPT 事件
        listener = new Listener(port);
        // set the server port to the default listener port.
        this.port = listener.getAddress().getPort();
        // 创建客户端连接管理器 ConnectionManager
        connectionManager = new ConnectionManager();
        this.rpcMetrics = RpcMetrics.create(this, conf);
        this.rpcDetailedMetrics = RpcDetailedMetrics.create(this.port);
```

```
        this.tcpNoDelay = conf.getBoolean(
                CommonConfigurationKeysPublic.IPC_SERVER_TCPNODELAY_KEY,
                CommonConfigurationKeysPublic.IPC_SERVER_TCPNODELAY_DEFAULT);

        this.setLogSlowRPC(conf.getBoolean(
                CommonConfigurationKeysPublic.IPC_SERVER_LOG_SLOW_RPC,
                CommonConfigurationKeysPublic.IPC_SERVER_LOG_SLOW_RPC_DEFAULT));

        // Create the responder here
        // 创建 Responder 线程
        responder = new Responder();

        if (secretManager != null || UserGroupInformation.isSecurityEnabled()) {
            SaslRpcServer.init(conf);
            saslPropsResolver = SaslPropertiesResolver.getInstance(conf);
        }

        this.exceptionsHandler.addTerseLoggingExceptions(StandbyException.class);
    }
```

1. 创建 CallQueueManager

```
public CallQueueManager(Class<? extends BlockingQueue<E>> backingClass,
                        Class<? extends RpcScheduler> schedulerClass,
                        boolean clientBackOffEnabled, int maxQueueSize, String
namespace,
                        Configuration conf) {
        int priorityLevels = parseNumLevels(namespace, conf);
        // 创建 DefaultRpcScheduler 对象
        this.scheduler = createScheduler(schedulerClass, priorityLevels,
                namespace, conf);
        // 创建 LinkedBlockingQueue 对象
        BlockingQueue<E> bq = createCallQueueInstance(backingClass,
                priorityLevels, maxQueueSize, namespace, conf);
        this.clientBackOffEnabled = clientBackOffEnabled;
        // 创建两个原子引用 LinkedBlockingQueue
        this.putRef = new AtomicReference<BlockingQueue<E>>(bq);
        this.takeRef = new AtomicReference<BlockingQueue<E>>(bq);
        LOG.info("Using callQueue: " + backingClass + " queueCapacity: " +
                maxQueueSize + " scheduler: " + schedulerClass);
    }
```

2. 创建 Listener 线程

```
Listener(int port) throws IOException {
```

```
            address = new InetSocketAddress(bindAddress, port);
            // Create a new server socket and set to non-blocking mode
            acceptChannel = ServerSocketChannel.open();
            acceptChannel.configureBlocking(false);

            // Bind the server socket to the local host and port
            bind(acceptChannel.socket(), address, backlogLength, conf, portRangeConfig);
            // Could be an ephemeral port
            this.listenPort = acceptChannel.socket().getLocalPort();
            Thread.currentThread().setName("Listener at " +
                    bindAddress + "/" + this.listenPort);
            // create a selector;
            selector = Selector.open();
            // 默认 Reader 数组大小 1
            readers = new Reader[readThreads];
            for (int i = 0; i < readThreads; i++) {
                // 创建 Reader 线程并启动
                Reader reader = new Reader(
                        "Socket Reader #" + (i + 1) + " for port " + port);
                readers[i] = reader;
                reader.start();
            }

            // Register accepts on the server socket with the selector
            acceptChannel.register(selector, SelectionKey.OP_ACCEPT);
            this.setName("IPC Server listener on " + port);
            this.setDaemon(true);
        }
```

2.1 创建 Reader 线程

```
Reader(String name) throws IOException {
            super(name);

            // 创建 LinkedBlockingQueue 默认值 100
            this.pendingConnections =
                    new
LinkedBlockingQueue<Connection>(readerPendingConnectionQueue);
            // open one selector to loop socket connection
            this.readSelector = Selector.open();
        }
```

3. 创建 ConnectionManager

```
ConnectionManager() {
```

```
                this.idleScanTimer = new Timer(
                        "IPC Server idle connection scanner for port " + getPort(), true);
                this.idleScanThreshold = conf.getInt(
                        CommonConfigurationKeysPublic.IPC_CLIENT_IDLETHRESHOLD_KEY,

CommonConfigurationKeysPublic.IPC_CLIENT_IDLETHRESHOLD_DEFAULT);
                this.idleScanInterval = conf.getInt(

CommonConfigurationKeys.IPC_CLIENT_CONNECTION_IDLESCANINTERVAL_KEY,

CommonConfigurationKeys.IPC_CLIENT_CONNECTION_IDLESCANINTERVAL_DEFAULT);
                this.maxIdleTime = 2 * conf.getInt(

CommonConfigurationKeysPublic.IPC_CLIENT_CONNECTION_MAXIDLETIME_KEY,

CommonConfigurationKeysPublic.IPC_CLIENT_CONNECTION_MAXIDLETIME_DEFAULT);
                this.maxIdleToClose = conf.getInt(
                        CommonConfigurationKeysPublic.IPC_CLIENT_KILL_MAX_KEY,
                        CommonConfigurationKeysPublic.IPC_CLIENT_KILL_MAX_DEFAULT);
                this.maxConnections = conf.getInt(

CommonConfigurationKeysPublic.IPC_SERVER_MAX_CONNECTIONS_KEY,

CommonConfigurationKeysPublic.IPC_SERVER_MAX_CONNECTIONS_DEFAULT);
                // create a set with concurrency -and- a thread-safe iterator, add 2
                // for listener and idle closer threads
                this.connections = Collections.newSetFromMap(
                        new ConcurrentHashMap<Connection, Boolean>(
                                maxQueueSize, 0.75f, readThreads + 2));
                this.userToConnectionsMap = new ConcurrentHashMap<>();
            }
```

4. 创建 Responder 线程

```
        Responder() throws IOException {
                this.setName("IPC Server Responder");
                this.setDaemon(true);
                writeSelector = Selector.open(); // create a selector
                pending = 0;
            }
```

1.3.2.2.2 注册协议及其实现类

```
// Register    protocol and its impl for rpc calls
```

```
        void registerProtocolAndImpl(RpcKind rpcKind, Class<?> protocolClass,
                                     Object protocolImpl) {
            // 获取协议接口 @ProtocolInfo 注解的 protocolName 属性对应的值
            String protocolName = RPC.getProtocolName(protocolClass);
            long version;
            try {
                // 获取协议接口 @ProtocolInfo 注解的 protocolVersion 属性对应的值
                version = RPC.getProtocolVersion(protocolClass);
            } catch (Exception ex) {
                LOG.warn("Protocol " + protocolClass +
                        " NOT registered as cannot get protocol version ");
                return;
            }
            // 获取协议容器 Map
            getProtocolImplMap(rpcKind)
                    // 协议及其协议实现类添加到容器 Map
                    .put(
                            new ProtoNameVer(protocolName, version),
                            new ProtoClassProtoImpl(protocolClass, protocolImpl));
            if (LOG.isDebugEnabled()) {
                LOG.debug("RpcKind = " + rpcKind + " Protocol Name = " + protocolName +
                        " version=" + version +
                        " ProtocolImpl=" + protocolImpl.getClass().getName() +
                        " protocolClass=" + protocolClass.getName());
            }
        }
```

1.3.3 启动 RPC.Server

```
/**
     * Starts the service.  Must be called before any calls will be handled.
     */
    public synchronized void start() {
        // 启动 Responder 线程 (本质调用 Responder run())
        responder.start();
        // 启动 Listener 线程 (本质调用 Listener run())
        listener.start();
        if (auxiliaryListenerMap != null && auxiliaryListenerMap.size() > 0) {
            for (Listener newListener : auxiliaryListenerMap.values()) {
                newListener.start();
            }
        }
```

```
        // 创建 Handler 线程数组 默认大小 1
        handlers = new Handler[handlerCount];
        // 初始化 Handler 线程并启动
        for (int i = 0; i < handlerCount; i++) {
            handlers[i] = new Handler(i);
            handlers[i].start();
        }
    }
```

1.3.4 RPC.Server 接收 Client 请求

1.3.4.1 Listener 线程监听 Client 连接请求

备注：调用 Listener 线程的 run()

```
@Override
        public void run() {
            LOG.info(Thread.currentThread().getName() + ": starting");
            SERVER.set(Server.this);
            // 定时扫描非激活状态的 Connection 并清除 避免 OOM
            connectionManager.startIdleScan();

            while (running) {
                SelectionKey key = null;
                try {
                    // 阻塞等待 Client 端 OP_ACCEPT 事件
                    getSelector().select();
                    Iterator<SelectionKey> iter = getSelector().selectedKeys().iterator();
                    while (iter.hasNext()) {
                        key = iter.next();
                        iter.remove();
                        try {
                            if (key.isValid()) {
                                if (key.isAcceptable())
                                    // 执行接收 Client 端 OP_ACCEPT 事件
                                    doAccept(key);
                            }
                        } catch (IOException e) {
                        }
```

```
                                key = null;
                            }
                        } catch (OutOfMemoryError e) {
                        ......
                        } catch (Exception e) {
                        ......
                        }
                    }
                ......
            }
```

1.3.4.1.1 doAccept() 核心业务逻辑

```
void doAccept(SelectionKey key) throws InterruptedException, IOException, OutOfMemoryError {
                    ServerSocketChannel server = (ServerSocketChannel) key.channel();
                    SocketChannel channel;
                    // 接收 Client 端的 SocketChannel 通道
                    while ((channel = server.accept()) != null) {
                        // 设置 SocketChannel 属性
                        channel.configureBlocking(false);
                        channel.socket().setTcpNoDelay(tcpNoDelay);
                        channel.socket().setKeepAlive(true);

                        // 轮询获取 Reader 线程
                        Reader reader = getReader();
                        // 封装 SocketChannel 为 Connection 对象并添加到 ConnectionManager 的 Set 集合
                        Connection c = connectionManager.register(channel, this.listenPort);
                        // If the connectionManager can't take it, close the connection.
                        if (c == null) {
                            if (channel.isOpen()) {
                                IOUtils.cleanup(null, channel);
                            }
                            connectionManager.droppedConnections.getAndIncrement();
                            continue;
                        }
                        // 绑定 Connection 到 SelectionKey 以便后续通过 SelectionKey.attachment() 获取对应的 Channel
                        key.attach(c);  // so closeCurrentConnection can get the object
                        // 将 Connection 添加到 Reader 线程的 LinkedBlockingQueue 阻塞队列并唤醒 Selector
                        reader.addConnection(c);
                    }
                }
```

1.3.4.2 Reader 线程监听阻塞队列是否有 Connection

备注：调用 Reader 线程的 run() 核心代码如下

```
private synchronized void doRunLoop() {
                        while (running) {
                            SelectionKey key = null;
                            try {
                                int size = pendingConnections.size();
                                for (int i = size; i > 0; i--) {
                                    // 弹出 Connection
                                    Connection conn = pendingConnections.take();
                                    // 往 Reader 线程的 NIO Selector 注册 OP_READ 事件并
绑定 Connection
                                    conn.channel.register(readSelector,     SelectionKey.OP_READ,
conn);
                                }
                                // 被 Listener 线程唤醒
                                readSelector.select();
                                // 第一次被 Listener 线程唤醒 iter 为空
                                Iterator<SelectionKey> iter = readSelector.selectedKeys().iterator();
                                while (iter.hasNext()) {
                                    key = iter.next();
                                    iter.remove();
                                    try {
                                        if (key.isReadable()) {
                                            // 监听到 OP_READ 事件 执行读取
SocketChannel 数据
                                            doRead(key);
                                        }
                                    } catch (CancelledKeyException cke) {
                                        ......
                                    }
                                    key = null;
                                }
                            } catch (InterruptedException e) {
                                ......
                        }
                    }
```

1.3.4.2.1 doRead() 核心业务逻辑

```
void doRead(SelectionKey key) throws InterruptedException {
                int count;
                // 获取 SelectionKey 绑定对象 也即 Connection
                Connection c = (Connection) key.attachment();
                if (c == null) {
                        return;
                }
                // 更新 Connection 上次连接时间戳
                c.setLastContact(Time.now());

                try {
                        // 读取 Connection 的 SocketChannel 数据区并处理
                        count = c.readAndProcess();
                } catch (InterruptedException ieo) {
                        LOG.info(Thread.currentThread().getName() + ": readAndProcess caught
InterruptedException", ieo);
                        throw ieo;
                } catch (Exception e) {
                        // Any exceptions that reach here are fatal unexpected internal errors
                        // that could not be sent to the client.
                        LOG.info(Thread.currentThread().getName() +
                                        ": readAndProcess from client " + c +
                                        " threw exception [" + e + "]", e);
                        count = -1; //so that the (count < 0) block is executed
                }
                // setupResponse will signal the connection should be closed when a
                // fatal response is sent.
                if (count < 0 || c.shouldClose()) {
                        closeConnection(c);
                        c = null;
                } else {
                        c.setLastContact(Time.now());
                }
        }
```

1 读取 RPC Request 数据区

```
public int readAndProcess() throws IOException, InterruptedException {
                while (!shouldClose()) { // stop if a fatal response has been sent.
                        // dataLengthBuffer is used to read "hrpc" or the rpc-packet length
                        int count = -1;
                        // 判断数据长度 buffer 是否可以写 一般情况下都是数据长度为 4
                        if (dataLengthBuffer.remaining() > 0) {
```

```
                    // 读取数据长度到 dataLengthBuffer
                    count = channelRead(channel, dataLengthBuffer);
                    if (count < 0 || dataLengthBuffer.remaining() > 0)
                        return count;
                }

                if (!connectionHeaderRead) {
                    // Every connection is expected to send the header;
                    // so far we read "hrpc" of the connection header.
                    if (connectionHeaderBuf == null) {
                        // for the bytes that follow "hrpc", in the connection header
                        // 申请 3 字节缓存数据头部 header 信息
                        connectionHeaderBuf = ByteBuffer.allocate(HEADER_LEN_AFTER_HRPC_PART);
                    }
                    // 读取头部 header 信息 (3 个字节)
                    count = channelRead(channel, connectionHeaderBuf);
                    if (count < 0 || connectionHeaderBuf.remaining() > 0) {
                        return count;
                    }
                    // 从头部 header 获取数据版本号
                    int version = connectionHeaderBuf.get(0);
                    // TODO we should add handler for service class later
                    this.setServiceClass(connectionHeaderBuf.get(1));
                    // 数据长度 buffer 变为可读
                    dataLengthBuffer.flip();

                    // Check if it looks like the user is hitting an IPC port
                    // with an HTTP GET - this is a common error, so we can
                    // send back a simple string indicating as much.
                    if (HTTP_GET_BYTES.equals(dataLengthBuffer)) {
                        setupHttpRequestOnIpcPortResponse();
                        return -1;
                    }

                    if (!RpcConstants.HEADER.equals(dataLengthBuffer)) {
                        LOG.warn("Incorrect RPC Header length from {}:{} "
                                + "expected length: {} got length: {}",
                            hostAddress, remotePort, RpcConstants.HEADER, dataLengthBuffer);
                        setupBadVersionResponse(version);
                        return -1;
                    }
                    if (version != CURRENT_VERSION) {
```

```
                //Warning is ok since this is not supposed to happen.
                LOG.warn("Version mismatch from " +
                         hostAddress + ":" + remotePort +
                         " got version " + version +
                         " expected version " + CURRENT_VERSION);
                setupBadVersionResponse(version);
                return -1;
            }

            // this may switch us into SIMPLE
            authProtocol = initializeAuthContext(connectionHeaderBuf.get(2));
            // 清除 buffer (不是请求 buffer 数据而是更新 buffer 的标识符)
            dataLengthBuffer.clear(); // clear to next read rpc packet len
            connectionHeaderBuf = null;
            connectionHeaderRead = true;
            continue; // connection header read, now read    4 bytes rpc packet len
        }

        if (data == null) { // just read 4 bytes -    length of RPC packet
            dataLengthBuffer.flip();
            // 读取数据长度 (4 个字节表示 RPC 包的长度)
            dataLength = dataLengthBuffer.getInt();
            checkDataLength(dataLength);
            // Set buffer for reading EXACTLY the RPC-packet length and no more.
            // 申请指定大小的 ByteBuffer
            data = ByteBuffer.allocate(dataLength);
        }
        // Now read the RPC packet
        // 读取数据到 ByteBuffer
        count = channelRead(channel, data);

        // 读取指定数据长度完成 也即读取完成一个 RPC package
        if (data.remaining() == 0) {
            dataLengthBuffer.clear(); // to read length of future rpc packets
            data.flip();
            ByteBuffer requestData = data;
            data = null; // null out in case processOneRpc throws.
            boolean isHeaderRead = connectionContextRead;
            // 处理一个 RPC 请求
            processOneRpc(requestData);
            // the last rpc-request we processed could have simply been the
            // connectionContext; if so continue to read the first RPC.
            if (!isHeaderRead) {
                continue;
```

```
                }
            }
            return count;
        }
        return -1;
    }
```

2 处理 RPC Request 请求

```
private void processOneRpc(ByteBuffer bb)
            throws IOException, InterruptedException {
        // exceptions that escape this method are fatal to the connection.
        // setupResponse will use the rpc status to determine if the connection
        // should be closed.
        int callId = -1;
        int retry = RpcConstants.INVALID_RETRY_COUNT;
        try {
            // 封装数据 ByteBuffer 为 Buffer 对象 (Buffer 底层还是维护一个 ByteBuffer)
            final RpcWritable.Buffer buffer = RpcWritable.Buffer.wrap(bb);
            // 读取数据区的 RpcRequestHeaderProto (通过依次读取字节 因为 RpcRequestHeaderProto 对象的字节固定)
            final RpcRequestHeaderProto header =
                    getMessage(RpcRequestHeaderProto.getDefaultInstance(), buffer);
            callId = header.getCallId();
            retry = header.getRetryCount();
            if (LOG.isDebugEnabled()) {
                LOG.debug(" got #" + callId);
            }
            checkRpcHeaders(header);

            if (callId < 0) { // callIds typically used during connection setup
                processRpcOutOfBandRequest(header, buffer);
            } else if (!connectionContextRead) {
                throw new FatalRpcServerException(
                        RpcErrorCodeProto.FATAL_INVALID_RPC_HEADER,
                        "Connection context not established");
            } else {
                // 处理 RPC 请求
                processRpcRequest(header, buffer);
            }
        } catch (RpcServerException rse) {
            .....
        }
    }
```

```
private void processRpcRequest(RpcRequestHeaderProto header,
                                RpcWritable.Buffer buffer) throws
RpcServerException,
        InterruptedException {
    // 基于 rpcKind 获取 RpcProtobufRequest
    Class<? extends Writable> rpcRequestClass =
            getRpcRequestWrapper(header.getRpcKind());
    if (rpcRequestClass == null) {
        LOG.warn("Unknown rpc kind " + header.getRpcKind() +
                " from client " + getHostAddress());
        final String err = "Unknown rpc kind in rpc header" +
                header.getRpcKind();
        throw new FatalRpcServerException(
                RpcErrorCodeProto.FATAL_INVALID_RPC_HEADER, err);
    }
    Writable rpcRequest;
    try {
        // Read the rpc request
        // 读取 rpc request 字节反射创建 RpcProtobufRequest 对象
        rpcRequest = buffer.newInstance(rpcRequestClass, conf);
    } catch (RpcServerException rse) { // lets tests inject failures.
        throw rse;
    } catch (Throwable t) { // includes runtime exception from newInstance
        LOG.warn("Unable to read call parameters for client " +
                getHostAddress() + "on connection protocol " +
                this.protocolName + " for rpcKind " + header.getRpcKind(), t);
        String err = "IPC server unable to read call parameters: " + t.getMessage();
        throw new FatalRpcServerException(
                RpcErrorCodeProto.FATAL_DESERIALIZING_REQUEST, err);
    }

    TraceScope traceScope = null;
    if (header.hasTraceInfo()) {
        if (tracer != null) {
            // If the incoming RPC included tracing info, always continue the
            // trace
            SpanId parentSpanId = new SpanId(
                    header.getTraceInfo().getTraceId(),
                    header.getTraceInfo().getParentId());
            traceScope = tracer.newScope(
                    RpcClientUtil.toTraceName(rpcRequest.toString()),
                    parentSpanId);
            traceScope.detach();
```

```
            }
        }

        CallerContext callerContext = null;
        if (header.hasCallerContext()) {
            callerContext =
                    new CallerContext.Builder(header.getCallerContext().getContext())
                            .setSignature(header.getCallerContext().getSignature()
                                    .toByteArray())
                            .build();
        }

        // 创建 RpcCall 对象 封装一个 rpc request
        RpcCall call = new RpcCall(
                // this -> 当前 Connection
                this,
                header.getCallId(),
                header.getRetryCount(),
                rpcRequest,
                ProtoUtil.convert(header.getRpcKind()),
                header.getClientId().toByteArray(),
                traceScope,
                callerContext);

        // Save the priority level assignment by the scheduler
        call.setPriorityLevel(callQueue.getPriorityLevel(call));
        call.markCallCoordinated(false);
        if (alignmentContext != null && call.rpcRequest != null &&
                (call.rpcRequest instanceof ProtobufRpcEngine.RpcProtobufRequest)) {
            // if call.rpcRequest is not RpcProtobufRequest, will skip the following
            // step and treat the call as uncoordinated. As currently only certain
            // ClientProtocol methods request made through RPC protobuf needs to be
            // coordinated.
            String methodName;
            String protoName;
            ProtobufRpcEngine.RpcProtobufRequest req =
                    (ProtobufRpcEngine.RpcProtobufRequest) call.rpcRequest;
            try {
                methodName = req.getRequestHeader().getMethodName();
                protoName = req.getRequestHeader().getDeclaringClassProtocolName();
                if (alignmentContext.isCoordinatedCall(protoName, methodName)) {
                    call.markCallCoordinated(true);
                    long stateId;
                    stateId = alignmentContext.receiveRequestState(
```

```
                                        header, getMaxIdleTime());
                                call.setClientStateId(stateId);
                            }
                        } catch (IOException ioe) {
                            throw new RpcServerException("Processing RPC request caught ", ioe);
                        }
                    }

                    try {
                        // 将 RpcCall 对象添加到 CallQueueManager 的 putRef 属性原子引用的阻塞队列中 等待 Handler 线程处理
                        internalQueueCall(call);
                    } catch (RpcServerException rse) {
                        throw rse;
                    } catch (IOException ioe) {
                        throw new FatalRpcServerException(
                                RpcErrorCodeProto.ERROR_RPC_SERVER, ioe);
                    }
                    incRpcCount();  // Increment the rpc count
                }
```

1.3.4.3 Handler 线程处理 Rpc Request

备注：调用 Handler 线程的 run()

```
@Override
        public void run() {
            LOG.debug(Thread.currentThread().getName() + ": starting");
            SERVER.set(Server.this);
            while (running) {
                TraceScope traceScope = null;
                Call call = null;
                long startTimeNanos = 0;
                // True iff the connection for this call has been dropped.
                // Set to true by default and update to false later if the connection
                // can be succesfully read.
                boolean connDropped = true;

                try {
                    // 从 CallQueueManager 阻塞队列弹出一个 RpcCall
                    call = callQueue.take(); // pop the queue; maybe blocked here
                    startTimeNanos = Time.monotonicNowNanos();
                    if (alignmentContext != null && call.isCallCoordinated() &&
```

```
                                    call.getClientStateId()                                    >
alignmentContext.getLastSeenStateId()) {
                                // Re-queue the call and continue
                                requeueCall(call);
                                continue;
                            }
                            if (LOG.isDebugEnabled()) {
                                LOG.debug(Thread.currentThread().getName() + ": " + call + " for
RpcKind " + call.rpcKind);
                            }
                            // 当前线程缓存 RpcCall
                            CurCall.set(call);
                            if (call.traceScope != null) {
                                call.traceScope.reattach();
                                traceScope = call.traceScope;
                                traceScope.getSpan().addTimelineAnnotation("called");
                            }
                            // always update the current call context
                            CallerContext.setCurrent(call.callerContext);
                            UserGroupInformation remoteUser = call.getRemoteUser();
                            connDropped = !call.isOpen();
                            if (remoteUser != null) {
                                remoteUser.doAs(call);
                            } else {
                                // 执行 RpcCall run()
                                call.run();
                            }
                        } catch (InterruptedException e) {
                            if (running) {                          // unexpected -- log it
                                LOG.info(Thread.currentThread().getName()    +    "    unexpectedly
interrupted", e);
                                if (traceScope != null) {
                                    traceScope.getSpan().addTimelineAnnotation("unexpectedly
interrupted: " +
                                            StringUtils.stringifyException(e));
                                }
                            }
                        } catch (Exception e) {
                            LOG.info(Thread.currentThread().getName() + " caught an exception",
e);
                            if (traceScope != null) {
                                traceScope.getSpan().addTimelineAnnotation("Exception: " +
                                        StringUtils.stringifyException(e));
                            }
```

```
                } finally {
                    // 清除当前线程缓存 RpcCall
                    CurCall.set(null);
                    IOUtils.cleanupWithLogger(LOG, traceScope);
                    if (call != null) {
                        updateMetrics(call, startTimeNanos, connDropped);
                        ProcessingDetails.LOG.debug(
                                "Served: [{}]{} name={} user={} details={}",
                                call, (call.isResponseDeferred() ? ", deferred" : ""),
                                call.getDetailedMetricsName(), call.getRemoteUser(),
                                call.getProcessingDetails());
                    }
                }
            }
            LOG.debug(Thread.currentThread().getName() + ": exiting");
        }
```

1.3.4.3.1 执行 RPC Request 的核心业务逻辑

备注：RpcCall.run()

```
@Override
        public Void run() throws Exception {
            if (!connection.channel.isOpen()) {
                Server.LOG.info(Thread.currentThread().getName() + ": skipped " + this);
                return null;
            }

            long startNanos = Time.monotonicNowNanos();
            Writable value = null;
            // 创建 ResponseParams 对象 以便返回 Rpc 请求
            ResponseParams responseParams = new ResponseParams();

            try {
                // 执行 Rpc 请求
                value = call(
                        rpcKind,
                        connection.protocolName,
                        rpcRequest,
                        timestampNanos);
            } catch (Throwable e) {
                populateResponseParamsOnError(e, responseParams);
            }
            if (!isResponseDeferred()) {
                long deltaNanos = Time.monotonicNowNanos() - startNanos;
```

```
                ProcessingDetails details = getProcessingDetails();

                details.set(Timing.PROCESSING, deltaNanos, TimeUnit.NANOSECONDS);
                deltaNanos -= details.get(Timing.LOCKWAIT, TimeUnit.NANOSECONDS);
                deltaNanos -= details.get(Timing.LOCKSHARED, TimeUnit.NANOSECONDS);
                deltaNanos -= details.get(Timing.LOCKEXCLUSIVE, TimeUnit.NANOSECONDS);
                details.set(Timing.LOCKFREE, deltaNanos, TimeUnit.NANOSECONDS);
                startNanos = Time.monotonicNowNanos();

                // 设置当前 RpcCall 的返回值参数
                setResponseFields(value, responseParams);
                // 发送 Rpc Request 请求结果
                sendResponse();

                deltaNanos = Time.monotonicNowNanos() - startNanos;
                details.set(Timing.RESPONSE, deltaNanos, TimeUnit.NANOSECONDS);
            } else {
                if (LOG.isDebugEnabled()) {
                    LOG.debug("Deferring response for callId: " + this.callId);
                }
            }
            return null;
        }
```

1 通过读取 RPC Request 的字节数据反序列化得到具体的执行类以及方法并返回结果

备注：RPC.call()

```
 @Override
        public Writable call(RPC.RpcKind rpcKind, String protocol,
                             Writable rpcRequest, long receiveTime) throws Exception {
            // 获取 Rpc 执行类 也即 ProtoBufRpcInvoker
            return getRpcInvoker(rpcKind)
                    .call(this, protocol, rpcRequest, receiveTime);
        }
```

备注：ProtoBufInvoker.call()

```
public Writable call(RPC.Server server, String connectionProtocolName,
                                    Writable writableRequest, long receiveTime) throws
Exception {
                // 强转为 RpcProtobufRequest
                RpcProtobufRequest request = (RpcProtobufRequest) writableRequest;
                // 获取 Rpc Request 头部 header
```

```
                RequestHeaderProto rpcRequest = request.getRequestHeader();
                // 获取 Rpc Request 执行方法名称
                String methodName = rpcRequest.getMethodName();

                // 获取 Rpc Request 执行方法全类名
                String declaringClassProtoName =
                        rpcRequest.getDeclaringClassProtocolName();
                long clientVersion = rpcRequest.getClientProtocolVersion();
                if (server.verbose)
                    LOG.info("Call: connectionProtocolName=" + connectionProtocolName +
                            ", method=" + methodName);

                // 获取 Rpc Request 请求处理类
                ProtoClassProtoImpl protocolImpl = getProtocolImpl(server,
                        declaringClassProtoName, clientVersion);
                BlockingService service = (BlockingService) protocolImpl.protocolImpl;
                // 通过 Rpc Request 处理类以及执行方法名称得到具体的执行方法描述
器
                MethodDescriptor methodDescriptor = service.getDescriptorForType()
                        .findMethodByName(methodName);
                if (methodDescriptor == null) {
                    String msg = "Unknown method " + methodName + " called on "
                            + connectionProtocolName + " protocol.";
                    LOG.warn(msg);
                    throw new RpcNoSuchMethodException(msg);
                }
                Message prototype = service.getRequestPrototype(methodDescriptor);
                // Rpc Request 请求参数
                Message param = request.getValue(prototype);

                Message result;
                // 从当前线程获取当前 RpcCall 对象
                Call currentCall = Server.getCurCall().get();
                try {
                    server.rpcDetailedMetrics.init(protocolImpl.protocolClass);
                    currentCallInfo.set(new CallInfo(server, methodName));
                    currentCall.setDetailedMetricsName(methodName);
                    // 执行具体的 Rpc Request 处理方法并返回值
                    result = service.callBlockingMethod(methodDescriptor, null, param);
                    // Check if this needs to be a deferred response,
                    // by checking the ThreadLocal callback being set
                    if (currentCallback.get() != null) {
                        currentCall.deferResponse();
                        currentCallback.set(null);
```

```
                        return null;
                    }
                } catch (ServiceException e) {
                    Exception exception = (Exception) e.getCause();
                    currentCall.setDetailedMetricsName(
                            exception.getClass().getSimpleName());
                    throw (Exception) e.getCause();
                } catch (Exception e) {
                    currentCall.setDetailedMetricsName(e.getClass().getSimpleName());
                    throw e;
                } finally {
                    currentCallInfo.set(null);
                }
                // 最终执行完成具体的 Rpc Request 请求的具体方法返回结果
                return RpcWritable.wrap(result);
            }
        }
    }
```

2 处理 RPC Request 请求结果

备注：RpcCall.doResponse()

```
@Override
        void doResponse(Throwable t, RpcStatusProto status) throws IOException {
            RpcCall call = this;
            if (t != null) {
                if (status == null) {
                    status = RpcStatusProto.FATAL;
                }
                // clone the call to prevent a race with another thread stomping
                // on the response while being sent.  the original call is
                // effectively discarded since the wait count won't hit zero
                call = new RpcCall(this);
                setupResponse(call, status, RpcErrorCodeProto.ERROR_RPC_SERVER,
                        null, t.getClass().getName(), StringUtils.stringifyException(t));
            } else {
                // 设置 Rpc Request 返回值头部信息以及返回字节数据
                setupResponse(call, call.responseParams.returnStatus,
                        call.responseParams.detailedErr, call.rv,
                        call.responseParams.errorClass,
                        call.responseParams.error);
            }
            // 将 Rpc Request 处理结果发送给 Client 端 (先 put 到当前 Connection 的
response 阻塞队列 等待 Responder 线程执行)
```

```
                connection.sendResponse(call);
            }
```

```
 // ipc reader threads should invoke this directly, whereas handlers
            // must invoke call.sendResponse to allow lifecycle management of
            // external, postponed, deferred calls, etc.
            private void sendResponse(RpcCall call) throws IOException {
                // 将 Rpc Request 请求结果添加到当前 Connection 的 response 柱塞队列等待 Responder 线程处理返回给 Client 端
                responder.doRespond(call);
            }
```

备注：Responder.doRespond()

```
void doRespond(RpcCall call) throws IOException {
                synchronized (call.connection.responseQueue) {
                    // must only wrap before adding to the responseQueue to prevent
                    // postponed responses from being encrypted and sent out of order.
                    if (call.connection.useWrap) {
                        wrapWithSasl(call);
                    }
                    // 将 Rpc Request 请求结果添加到当前 Connection 对象的 response 阻塞队列尾部
                    call.connection.responseQueue.addLast(call);
                    // 如果当前 Connection 对象的 response 阻塞队列大小为 1 直接由 Handler 线程返回 否则等待 Responder 线程处理
                    if (call.connection.responseQueue.size() == 1) {
                        processResponse(call.connection.responseQueue, true);
                    }
                }
            }
```

```
 // Processes one response. Returns true if there are no more pending
            // data for this channel.
            //
            private boolean processResponse(LinkedList<RpcCall> responseQueue,
                                            boolean inHandler) throws IOException {
                boolean error = true;
                boolean done = false;       // there is more data for this channel.
                int numElements = 0;
                RpcCall call = null;
                try {
                    synchronized (responseQueue) {
                        //
                        // If there are no items for this channel, then we are done
```

```
                        //
                        numElements = responseQueue.size();
                        if (numElements == 0) {
                            error = false;
                            return true;                    // no more data for this channel.
                        }
                        //
                        // Extract the first call
                        // 弹出 RpcCall 对象 以便后续返回 Rpc 结果给 Client 端
                        call = responseQueue.removeFirst();
                        // 获取当前 Rpc Request SocketChannel 通道
                        SocketChannel channel = call.connection.channel;
                        if (LOG.isDebugEnabled()) {
                            LOG.debug(Thread.currentThread().getName() + ": responding to "
+ call);
                        }
                        //
                        // Send as much data as we can in the non-blocking fashion
                        // 执行将 Rpc Request 的结果返回给 Client 端
                        int numBytes = channelWrite(channel, call.rpcResponse);
                        if (numBytes < 0) {
                            return true;
                        }
                        if (!call.rpcResponse.hasRemaining()) {
                            //Clear out the response buffer so it can be collected
                            call.rpcResponse = null;
                            call.connection.decRpcCount();
                            if (numElements == 1) {    // last call fully processes.
                                done = true;                    // no more data for this channel.
                            } else {
                                done = false;                   // more calls pending to be sent.
                            }
                            if (LOG.isDebugEnabled()) {
                                LOG.debug(Thread.currentThread().getName() + ": responding
to " + call
                                        + " Wrote " + numBytes + " bytes.");
                            }
                        } else {
                            //
                            // If we were unable to write the entire response out, then
                            // insert in Selector queue.
                            // 如果一次性返回不了全部数据给 Client 端 则将当前
RpcCall 重新塞入 response 阻塞队列 后续数据由 Responder 线程处理
                            call.connection.responseQueue.addFirst(call);
```

```
                                if (inHandler) {
                                    // set the serve time when the response has to be sent later
                                    call.timestampNanos = Time.monotonicNowNanos();

                                    // 累计 pending 加 1 后续 Responder 线程进行处理
                                    incPending();
                                    try {
                                        // Wakeup the thread blocked on select, only then can the call
                                        // to channel.register() complete.
                                        // 唤醒 Responder 线程的 NIO Selector
                                        writeSelector.wakeup();
                                        // 将当前 Rpc Request 的 SocketChannel 注册 OP_WRITE 事件到 Responder 线程的 NIO Selector
                                        channel.register(writeSelector, SelectionKey.OP_WRITE, call);
                                    } catch (ClosedChannelException e) {
                                        //Its ok. channel might be closed else where.
                                        done = true;
                                    } finally {
                                        // pending 减 1 并唤醒 Responder 线程
                                        decPending();
                                    }
                                }
                                if (LOG.isDebugEnabled()) {
                                    LOG.debug(Thread.currentThread().getName() + ": responding to " + call
                                            + " Wrote partial " + numBytes + " bytes.");
                                }
                            }
                            error = false;                // everything went off well
                        }
                    } finally {
                        if (error && call != null) {
                            LOG.warn(Thread.currentThread().getName() + ", call " + call + ": output error");
                            done = true;                  // error. no more data for this channel.
                            closeConnection(call.connection);
                        }
                    }
                    return done;
                }
```

1.3.4.4 Responder 线程处理 Rpc Request 请求结果给 Client 端

备注：Responder.run()

```
 private void doRunLoop() {
                long lastPurgeTimeNanos = 0;      // last check for old calls.

                while (running) {
                    try {
                        // 阻塞等待 pending > 0
                        waitPending();          // If a channel is being registered, wait.
                        // 监听 OP_WRITE 事件
                        writeSelector.select(
                                TimeUnit.NANOSECONDS.toMillis(PURGE_INTERVAL_NANOS));
                        Iterator<SelectionKey> iter = writeSelector.selectedKeys().iterator();
                        while (iter.hasNext()) {
                            SelectionKey key = iter.next();
                            iter.remove();
                            try {
                                if (key.isWritable()) {
                                    // 将 Rpc Request 请求结果返回给 Client 端
                                    doAsyncWrite(key);
                                }
                            } catch (CancelledKeyException cke) {
                                // something else closed the connection, ex. reader or the
                                // listener doing an idle scan.  ignore it and let them clean
                                // up
                                RpcCall call = (RpcCall) key.attachment();
                                if (call != null) {
                                    LOG.info(Thread.currentThread().getName() +
                                            ": connection aborted from " + call.connection);
                                }
                            } catch (IOException e) {
                                LOG.info(Thread.currentThread().getName() + ": doAsyncWrite
threw exception " + e);
                            }
                        }
                        long nowNanos = Time.monotonicNowNanos();
                        if (nowNanos < lastPurgeTimeNanos + PURGE_INTERVAL_NANOS) {
                            continue;
                        }
                        lastPurgeTimeNanos = nowNanos;
                        //
                        // If there were some calls that have not been sent out for a
```

```
                        // long time, discard them.
                        //
                        if (LOG.isDebugEnabled()) {
                            LOG.debug("Checking for old call responses.");
                        }
                        ArrayList<RpcCall> calls;

                        // get the list of channels from list of keys.
                        synchronized (writeSelector.keys()) {
                            calls = new ArrayList<RpcCall>(writeSelector.keys().size());
                            iter = writeSelector.keys().iterator();
                            while (iter.hasNext()) {
                                SelectionKey key = iter.next();
                                RpcCall call = (RpcCall) key.attachment();
                                if (call != null && key.channel() == call.connection.channel) {
                                    calls.add(call);
                                }
                            }
                        }

                        for (RpcCall call : calls) {
                            doPurge(call, nowNanos);
                        }
                    } catch (OutOfMemoryError e) {
                        //
                        // we can run out of memory if we have too many threads
                        // log the event and sleep for a minute and give
                        // some thread(s) a chance to finish
                        //
                        LOG.warn("Out of Memory in server select", e);
                        try {
                            Thread.sleep(60000);
                        } catch (Exception ie) {
                        }
                    } catch (Exception e) {
                        LOG.warn("Exception in Responder", e);
                    }
                }
            }
```

1.3.4.4.1 执行 Rpc Request 请求返回结果给 Client 端核心业务逻辑

```
private void doAsyncWrite(SelectionKey key) throws IOException {
            // 获取 SelectionKey 绑定的 RpcCall 对象
```

```
                RpcCall call = (RpcCall) key.attachment();
                if (call == null) {
                    return;
                }
                if (key.channel() != call.connection.channel) {
                    throw new IOException("doAsyncWrite: bad channel");
                }

                synchronized (call.connection.responseQueue) {
                    // 返回数据给 Client 端
                    if (processResponse(call.connection.responseQueue, false)) {
                        try {
                            // 成功写完数据给 Client 端 恢复 interestOps 为 0
                            key.interestOps(0);
                        } catch (CancelledKeyException e) {
                            /* The Listener/reader might have closed the socket.
                             * We don't explicitly cancel the key, so not sure if this will
                             * ever fire.
                             * This warning could be removed.
                             */
                            LOG.warn("Exception while changing ops : " + e);
                        }
                    }
                }
            }
```

如果还是没有完全返回数据给 Client 端 则循环 (但是不在注册 OP_WRITE 事件)

```
// Processes one response. Returns true if there are no more pending
        // data for this channel.
        //
        private boolean processResponse(LinkedList<RpcCall> responseQueue,
                                        boolean inHandler) throws IOException {
            boolean error = true;
            boolean done = false;       // there is more data for this channel.
            int numElements = 0;
            RpcCall call = null;
            try {
                synchronized (responseQueue) {
                    //
                    // If there are no items for this channel, then we are done
                    //
                    numElements = responseQueue.size();
                    if (numElements == 0) {
                        error = false;
```

```
                    return true;                // no more data for this channel.
                }
                //
                // Extract the first call
                // 弹出 RpcCall 对象 以便后续返回 Rpc 结果给 Client 端
                call = responseQueue.removeFirst();
                // 获取当前 Rpc Request SocketChannel 通道
                SocketChannel channel = call.connection.channel;
                if (LOG.isDebugEnabled()) {
                    LOG.debug(Thread.currentThread().getName() + ": responding to "
+ call);
                }
                //
                // Send as much data as we can in the non-blocking fashion
                // 执行将 Rpc Request 的结果返回给 Client 端
                int numBytes = channelWrite(channel, call.rpcResponse);
                if (numBytes < 0) {
                    return true;
                }
                if (!call.rpcResponse.hasRemaining()) {
                    //Clear out the response buffer so it can be collected
                    call.rpcResponse = null;
                    call.connection.decRpcCount();
                    if (numElements == 1) {    // last call fully processes.
                        done = true;             // no more data for this channel.
                    } else {
                        done = false;            // more calls pending to be sent.
                    }
                    if (LOG.isDebugEnabled()) {
                        LOG.debug(Thread.currentThread().getName() + ": responding
to " + call
                                + " Wrote " + numBytes + " bytes.");
                    }
                } else {
                    //
                    // If we were unable to write the entire response out, then
                    // insert in Selector queue.
                    // 如果一次性返回不了全部数据给 Client 端 则将当前
RpcCall 重新塞入 response 阻塞队列 后续数据由 Responder 线程处理
                    call.connection.responseQueue.addFirst(call);

                    if (inHandler) {
                        // set the serve time when the response has to be sent later
                        call.timestampNanos = Time.monotonicNowNanos();
```

```
                                // 累计 pending 加 1 后续 Responder 线程进行处理
                                incPending();
                                try {
                                    // Wakeup the thread blocked on select, only then can the call
                                    // to channel.register() complete.
                                    // 唤醒 Responder 线程的 NIO Selector
                                    writeSelector.wakeup();
                                    // 将当前 Rpc Request 的 SocketChannel 注册 OP_WRITE 事件到 Responder 线程的 NIO Selector
                                    channel.register(writeSelector, SelectionKey.OP_WRITE, call);
                                } catch (ClosedChannelException e) {
                                    //Its ok. channel might be closed else where.
                                    done = true;
                                } finally {
                                    // pending 减 1
                                    decPending();
                                }
                            }
                            if (LOG.isDebugEnabled()) {
                                LOG.debug(Thread.currentThread().getName() + ": responding to " + call
                                        + " Wrote partial " + numBytes + " bytes.");
                            }
                        }
                        error = false;                  // everything went off well
                    }
                } finally {
                    if (error && call != null) {
                        LOG.warn(Thread.currentThread().getName() + ", call " + call + ": output error");
                        done = true;                    // error. no more data for this channel.
                        closeConnection(call.connection);
                    }
                }
                return done;
            }
```

1.4 rpc-client 源码剖析

备注：RPC.getProxy()

```
public static <T> T getProxy(Class<T> protocol,
                                        long clientVersion,
                                        InetSocketAddress addr,
                                        Configuration conf)
                throws IOException {

            // 获取协议代理 ProtocolProxy
            return getProtocolProxy(protocol, clientVersion, addr, conf)
                        .getProxy();
      }
```

1.4.1 获取协议代理 ProtocolProxy 对象

```
public static <T> ProtocolProxy<T> getProtocolProxy(Class<T> protocol,
                                                                long clientVersion,
                                                                InetSocketAddress       addr,
Configuration conf)
                throws IOException {

            // Client 端获取协议代理
            return getProtocolProxy(protocol, clientVersion, addr, conf,
                        // 创建 StandardSocketFactory 对象
                        NetUtils.getDefaultSocketFactory(conf));
      }
```

```
public static <T> ProtocolProxy<T> getProtocolProxy(Class<T> protocol,
                                                                long clientVersion,
                                                                InetSocketAddress addr,
                                                                UserGroupInformation
ticket,
                                                                Configuration conf,
                                                                SocketFactory factory,
                                                                int rpcTimeout,
                                                                RetryPolicy
connectionRetryPolicy,
                                                                AtomicBoolean
fallbackToSimpleAuth)
                throws IOException {
```

```
        if (UserGroupInformation.isSecurityEnabled()) {
            SaslRpcServer.init(conf);
        }
        // 通过反射的方式创建 ProtobufRpcEngine 对象
        return getProtocolEngine(protocol, conf)
                // 获取 ProtocolProxy 对象
                .getProxy(protocol, clientVersion,
                        addr, ticket, conf, factory, rpcTimeout, connectionRetryPolicy,
                        fallbackToSimpleAuth, null);
    }
```

备注：ProtobufRpcEngine.getProxy()

```
public <T> ProtocolProxy<T> getProxy(Class<T> protocol, long clientVersion,
                                     InetSocketAddress addr,
UserGroupInformation ticket, Configuration conf,
                                     SocketFactory factory, int rpcTimeout,
RetryPolicy connectionRetryPolicy,
                                     AtomicBoolean fallbackToSimpleAuth,
AlignmentContext alignmentContext)
            throws IOException {

        // 创建 Invoker 对象
        final Invoker invoker = new Invoker(protocol, addr, ticket, conf, factory,
                rpcTimeout, connectionRetryPolicy, fallbackToSimpleAuth,
                alignmentContext);
        // 创建 ProtocolProxy 对象
        return new ProtocolProxy<T>(protocol,
                // JDK 动态代理标配操作
                (T) Proxy.newProxyInstance(
                        protocol.getClassLoader(), new Class[]{protocol}, invoker),
                false);
    }
```

```
public ProtocolProxy(Class<T> protocol, T proxy,
                     boolean supportServerMethodCheck) {
        // 协议接口类
        this.protocol = protocol;
        // 协议接口代理对象
        this.proxy = proxy;
        // 默认 false
        this.supportServerMethodCheck = supportServerMethodCheck;
    }
```

1.4.2 调用协议接口方法执行 RPC 请求调用 Invoker.invoke()

```
@Override
        public Message invoke(Object proxy, final Method method, Object[] args)
                throws ServiceException {
            long startTime = 0;
            if (LOG.isDebugEnabled()) {
                startTime = Time.now();
            }

            if (args.length != 2) { // RpcController + Message
                throw new ServiceException(
                        "Too many or few parameters for request. Method: ["
                                + method.getName() + "]" + ", Expected: 2, Actual: "
                                + args.length);
            }
            if (args[1] == null) {
                throw new ServiceException("null param while calling Method: ["
                        + method.getName() + "]");
            }

            // if Tracing is on then start a new span for this rpc.
            // guard it in the if statement to make sure there isn't
            // any extra string manipulation.
            Tracer tracer = Tracer.curThreadTracer();
            TraceScope traceScope = null;
            if (tracer != null) {
                traceScope = tracer.newScope(RpcClientUtil.methodToTraceString(method));
            }

            // 构建 Rpc Request 头部 Header 信息 (执行方法名称、协议接口名称、协议版本)
            RequestHeaderProto rpcRequestHeader = constructRpcRequestHeader(method);

            if (LOG.isTraceEnabled()) {
                LOG.trace(Thread.currentThread().getId() + ": Call -> " +
                        remoteId + ": " + method.getName() +
                        " {" + TextFormat.shortDebugString((Message) args[1]) + "}");
            }

            // 请求参数强转为 Message 对象
            final Message theRequest = (Message) args[1];
            final RpcWritable.Buffer val;
```

```
try {
    // 执行 Rpc Request
    val = (RpcWritable.Buffer) client.call(
            RPC.RpcKind.RPC_PROTOCOL_BUFFER,
            // 创建 Rpc Request RpcProtobufRequest 对象
            new RpcProtobufRequest(rpcRequestHeader, theRequest),
            remoteId, fallbackToSimpleAuth, alignmentContext);

} catch (Throwable e) {
    if (LOG.isTraceEnabled()) {
        LOG.trace(Thread.currentThread().getId() + ": Exception <- " +
                remoteId + ": " + method.getName() +
                " {" + e + "}");
    }
    if (traceScope != null) {
        traceScope.addTimelineAnnotation("Call got exception: " +
                e.toString());
    }
    throw new ServiceException(e);
} finally {
    if (traceScope != null) traceScope.close();
}

if (LOG.isDebugEnabled()) {
    long callTime = Time.now() - startTime;
    LOG.debug("Call: " + method.getName() + " took " + callTime + "ms");
}

// 如果 Client 端异步发送 Rpc Request 则异步处理返回结果
if (Client.isAsynchronousMode()) {
    final AsyncGet<RpcWritable.Buffer, IOException> arr
            = Client.getAsyncRpcResponse();
    final AsyncGet<Message, Exception> asyncGet
            = new AsyncGet<Message, Exception>() {
        @Override
        public Message get(long timeout, TimeUnit unit) throws Exception {
            return getReturnMessage(method, arr.get(timeout, unit));
        }

        @Override
        public boolean isDone() {
            return arr.isDone();
        }
    };
```

```
                    ASYNC_RETURN_MESSAGE.set(asyncGet);
                    return null;
                } else {
                    return getReturnMessage(method, val);
                }
            }
```

```
Writable call(RPC.RpcKind rpcKind, Writable rpcRequest,
                    ConnectionId remoteId, int serviceClass,
                    AtomicBoolean fallbackToSimpleAuth, AlignmentContext
alignmentContext)
            throws IOException {
        // 创建 Call 对象
        final Call call = createCall(rpcKind, rpcRequest);
        call.setAlignmentContext(alignmentContext);
        // 创建 Connection 对象 (继承 Thread 类)
        final Connection connection = getConnection(remoteId, call, serviceClass,
                fallbackToSimpleAuth);

        try {
            checkAsyncCall();
            try {
                // 发送 Rpc Request
                connection.sendRpcRequest(call);                    // send the rpc
request
            } catch (RejectedExecutionException e) {
                throw new IOException("connection has been closed", e);
            } catch (InterruptedException ie) {
                Thread.currentThread().interrupt();
                IOException ioe = new InterruptedIOException(
                        "Interrupted waiting to send RPC request to server");
                ioe.initCause(ie);
                throw ioe;
            }
        } catch (Exception e) {
            if (isAsynchronousMode()) {
                releaseAsyncCall();
            }
            throw e;
        }

        // 判断是否异步处理 Rpc Request 返回接口
        if (isAsynchronousMode()) {
            final AsyncGet<Writable, IOException> asyncGet
```

```
                    = new AsyncGet<Writable, IOException>() {
                @Override
                public Writable get(long timeout, TimeUnit unit)
                        throws IOException, TimeoutException {
                    boolean done = true;
                    try {
                        // 异步处理返回结果
                        final Writable w = getRpcResponse(call, connection, timeout, unit);
                        if (w == null) {
                            done = false;
                            throw new TimeoutException(call + " timed out "
                                    + timeout + " " + unit);
                        }
                        return w;
                    } finally {
                        if (done) {
                            releaseAsyncCall();
                        }
                    }
                }

                @Override
                public boolean isDone() {
                    synchronized (call) {
                        return call.done;
                    }
                }
            };

            ASYNC_RPC_RESPONSE.set(asyncGet);
            return null;
        } else {
            // 同步处理返回结果 (阻塞等待 将由 Connection.run() 接收到数据后唤醒)
            return getRpcResponse(call, connection, -1, null);
        }
    }
```

```
private Connection getConnection(ConnectionId remoteId,
                                 Call call, int serviceClass, AtomicBoolean
fallbackToSimpleAuth)
            throws IOException {
        if (!running.get()) {
            // the client is stopped
            throw new IOException("The client is stopped");
```

```
        }
        Connection connection;
        /* we could avoid this allocation for each RPC by having a
         * connectionsId object and with set() method. We need to manage the
         * refs for keys in HashMap properly. For now its ok.
         */
        while (true) {
            // These lines below can be shorten with computeIfAbsent in Java8
            connection = connections.get(remoteId);
            if (connection == null) {
                // 创建 Connection 对象
                connection = new Connection(remoteId, serviceClass);
                Connection existing = connections.putIfAbsent(remoteId, connection);
                if (existing != null) {
                    connection = existing;
                }
            }

            if (connection.addCall(call)) {
                break;
            } else {
                // This connection is closed, should be removed. But other thread could
                // have already known this closedConnection, and replace it with a new
                // connection. So we should call conditional remove to make sure we only
                // remove this closedConnection.
                connections.remove(remoteId, connection);
            }
        }

        // If the server happens to be slow, the method below will take longer to
        // establish a connection.
        // 跟 Server 端建立连接
        connection.setupIOstreams(fallbackToSimpleAuth);
        return connection;
    }
```

```
private synchronized void setupIOstreams(
                AtomicBoolean fallbackToSimpleAuth) {
            if (socket != null || shouldCloseConnection.get()) {
                return;
            }
            UserGroupInformation ticket = remoteId.getTicket();
            if (ticket != null) {
                final UserGroupInformation realUser = ticket.getRealUser();
```

```
                    if (realUser != null) {
                        ticket = realUser;
                    }
                }
                try {
                    connectingThread.set(Thread.currentThread());
                    if (LOG.isDebugEnabled()) {
                        LOG.debug("Connecting to " + server);
                    }
                    Span span = Tracer.getCurrentSpan();
                    if (span != null) {
                        span.addTimelineAnnotation("IPC client connecting to " + server);
                    }
                    short numRetries = 0;
                    Random rand = null;
                    while (true) {
                        // 启动 Client 端 SocketChannel 去连接 Server 端 ServerSocketChannel
                        setupConnection(ticket);
                        // 创建 IpcStreams 对象
                        ipcStreams = new IpcStreams(socket, maxResponseLength);
                        // 往 IpcStreams 流写入 Rpc Request 的头部信息
                        writeConnectionHeader(ipcStreams);
                        if (authProtocol == AuthProtocol.SASL) {
                            try {
                                authMethod = ticket
                                        .doAs(new PrivilegedExceptionAction<AuthMethod>() {
                                            @Override
                                            public AuthMethod run()
                                                    throws IOException, InterruptedException {
                                                return setupSaslConnection(ipcStreams);
                                            }
                                        });
                            } catch (IOException ex) {
                                if (saslRpcClient == null) {
                                    // whatever happened -it can't be handled, so rethrow
                                    throw ex;
                                }
                                // otherwise, assume a connection problem
                                authMethod = saslRpcClient.getAuthMethod();
                                if (rand == null) {
                                    rand = new Random();
```

```
                                    }
                                    handleSaslConnectionFailure(numRetries++,
maxRetriesOnSasl, ex,
                                            rand, ticket);
                                    continue;
                                }
                                if (authMethod != AuthMethod.SIMPLE) {
                                    // Sasl connect is successful. Let's set up Sasl i/o streams.
                                    ipcStreams.setSaslClient(saslRpcClient);
                                    // for testing
                                    remoteId.saslQop =
                                            (String)
saslRpcClient.getNegotiatedProperty(Sasl.QOP);
                                    LOG.debug("Negotiated QOP is :" + remoteId.saslQop);
                                    if (fallbackToSimpleAuth != null) {
                                        fallbackToSimpleAuth.set(false);
                                    }
                                } else if (UserGroupInformation.isSecurityEnabled()) {
                                    if (!fallbackAllowed) {
                                        throw new IOException("Server asks us to fall back to
SIMPLE " +
                                                "auth, but this client is configured to only allow
secure " +
                                                "connections.");
                                    }
                                    if (fallbackToSimpleAuth != null) {
                                        fallbackToSimpleAuth.set(true);
                                    }
                                }
                            }

                            if (doPing) {
                                ipcStreams.setInputStream(new PingInputStream(ipcStreams.in));
                            }

                            // 往 IpcStreams 流写入当前 Connection 上下文信息
                            writeConnectionContext(remoteId, authMethod);

                            // update last activity time
                            touch();

                            span = Tracer.getCurrentSpan();
                            if (span != null) {
                                span.addTimelineAnnotation("IPC client connected to " + server);
```

```
                    }

                    // start the receiver thread after the socket connection has been set
                    // up
                    // 调用 Connection.run()
                    start();
                    return;
                }
            } catch (Throwable t) {
                if (t instanceof IOException) {
                    markClosed((IOException) t);
                } else {
                    markClosed(new IOException("Couldn't set up IO streams: " + t, t));
                }
                close();
            } finally {
                connectingThread.set(null);
            }
        }
```

```
public void run() {
            if (LOG.isDebugEnabled())
                LOG.debug(getName() + ": starting, having connections "
                        + connections.size());

            try {
                while (waitForWork()) {//wait here for work - read or close connection
                    // 等待 Rpc Request 结果返回
                    receiveRpcResponse();
                }
            } catch (Throwable t) {
                // This truly is unexpected, since we catch IOException in receiveResponse
                // -- this is only to be really sure that we don't leave a client hanging
                // forever.
                LOG.warn("Unexpected error reading responses on connection " + this, t);
                markClosed(new IOException("Error reading responses", t));
            }

            close();

            if (LOG.isDebugEnabled())
                LOG.debug(getName() + ": stopped, remaining connections "
                        + connections.size());
        }
```

```
/* Receive a response.
             * Because only one receiver, so no synchronization on in.
             */
            private void receiveRpcResponse() {
                if (shouldCloseConnection.get()) {
                    return;
                }
                touch();

                try {
                    // 读取 Rpc Request 返回数据
                    ByteBuffer bb = ipcStreams.readResponse();
                    RpcWritable.Buffer packet = RpcWritable.Buffer.wrap(bb);
                    RpcResponseHeaderProto header =
                            packet.getValue(RpcResponseHeaderProto.getDefaultInstance());
                    checkResponse(header);

                    int callId = header.getCallId();
                    if (LOG.isDebugEnabled())
                        LOG.debug(getName() + " got value #" + callId);

                    RpcStatusProto status = header.getStatus();
                    if (status == RpcStatusProto.SUCCESS) {
                        Writable value = packet.newInstance(valueClass, conf);
                        final Call call = calls.remove(callId);
                        // 赋值操作
                        call.setRpcResponse(value);
                        if (call.alignmentContext != null) {
                            call.alignmentContext.receiveResponseState(header);
                        }
                    }
                    // verify that packet length was correct
                    if (packet.remaining() > 0) {
                        throw new RpcClientException("RPC response length mismatch");
                    }
                    if (status != RpcStatusProto.SUCCESS) { // Rpc Request failed
                        final String exceptionClassName = header.hasExceptionClassName() ?
                                header.getExceptionClassName() :
                                "ServerDidNotSetExceptionClassName";
                        final String errorMsg = header.hasErrorMsg() ?
                                header.getErrorMsg() : "ServerDidNotSetErrorMsg";
                        final RpcErrorCodeProto erCode =
                                (header.hasErrorDetail() ? header.getErrorDetail() : null);
                        if (erCode == null) {
```

```
                                LOG.warn("Detailed error code not set by server on rpc error");
                            }
                            RemoteException re = new RemoteException(exceptionClassName,
errorMsg, erCode);
                            if (status == RpcStatusProto.ERROR) {
                                final Call call = calls.remove(callId);
                                call.setException(re);
                            } else if (status == RpcStatusProto.FATAL) {
                                // Close the connection
                                markClosed(re);
                            }
                        }
                    } catch (IOException e) {
                        markClosed(e);
                    }
                }
```