Driver Development Part 5: Introduction to the Transport Device Interface

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Introduction to TDI Client drivers and more IRP handling.

Download source code - 41.1 Kb

Introduction

Welcome to the fifth installment of the driver development series. The title of this article is a little bit misleading. Yes, we will be writing a TDI Client for demonstration purposes however that is not the main goal of this tutorial. The main goal of this tutorial is to further explore how to handle and interact with IRPs. This tutorial will explore how to queue and handle the canceling of IRPs. The real title of this article should be "Introduction to IRP Handling" however it's not as catchy a title! Also, it's not a complete fib we will be doing this while demonstration implementing a TDI Client driver. So, I actually have to explain how that part is implemented as well. The supplied example is a very simple client/server chat program which we will be using to explore how to handle IRPs.

Sockets Refresher

We will first be starting off with something that you should probably already know. If you don't know you may want to read some other articles on the subject. Even so, I have supplied this quick refresher course as well as example source of how to implement winsock.

What is IP?

IP or "Internet Protocol" is essentially a protocol used to send data or packets between two computers. This protocol does not need any setup and only requires that, each machine on the network have a unique "IP Address". The "IP Address" can then be used to route packets between communication end points. This protocol provides routing but it does not provide reliability. Packets sent only by IP can arrive corrupted, out of order or not at all. There are however other protocols implemented on top of IP which provide these features. The "IP" Protocol lies at the Network Layer in the OSI model.

What is TCP?

TCP is known as "Transmission Control Protocol" and it sits on top of the "IP" protocol. This is also commonly referred to as "TCP/IP". The "IP" layer provides the routing and the "TCP" layer reliable, sequenced uncorrupted delivery of data. To distinguish between multiple TCP transmissions on the machine they are identified by a unique TCP port number. In this manner multiple applications or even the same application can open a communications pipeline and the underlying transport will be able to correctly route the data between each end point. The "TCP" protocol lies at the Transport in the OSI model. There are other protocols which then sit on top of TCP such as FTP, HTTP, etc. These protocols sit at the "Application Layer" of the OSI model.

Protocol Layering

In some sense any part of the communications stack can be replaced by an "equivalent" protocol. If FTP for example requires reliable transport and routing, then sitting on top of any protocol which provides this would still work. In that example if an application was using "SPX" instead of "TCP/IP" it shouldn't make a difference. In that sense if "TCP" or some implementation of "TCP" sat on top of an unreliable protocol like "IPX", it should work. The reason for "some implementation" should work is because, it obviously depends on how dependent the upper protocol is on the actual implementation and inner workings of the underlying protocol they are.

What are sockets?

A "socket" is generally referred to as a communications end point as implemented by a "sockets" library. The "sockets" library API was generally written to be a simple way (and portable in some cases) to implement networking applications from user mode. There are a few flavors of socket APIs but in Windows we use "WINSOCK". There are aspects of Winsock which can be implemented as portable (I once implemented a winsock application that was compiled on both Unix and Windows NT with minimal conflict but of course it was a very simple program) and there are others which are not directly portable.

Socket Server Application

The server side of a socket connection simply accepts incoming connections. Each new connection is given a separate handle so that the server can then communicate to each client individually. The following outlines the steps used in communications.

Step One: Create a Socket

The first step is to create a socket. The following code shows how to create a socket for streaming (TCP/IP).

```
hSocket = socket(PF_INET, SOCK_STREAM, 0);

if(hSocket == INVALID_SOCKET)
{
   /* Error */
}
```

This is then simply a handle to the network driver. You use this handle in other calls to the socket API.

Step Two: Bind the Socket

The second step is to bind a socket to a TCP port and IP Address. The following code demonstrates this behavior. The socket is created in our example simply using a number, however in general you should use macros to put the port into network byte order.

```
SockAddr.sin_family = PF_INET;
SockAddr.sin_port = htons(4000);      /* Must be in NETWORK BYTE ORDER */

/*
 * BIND the Socket to a Port
 */
uiErrorStatus =
       bind(hSocket, (struct sockaddr *)&SockAddr, sizeof(SOCKADDR_IN));

if(uiErrorStatus == INVALID_SOCKET)
{
   /* Error */
}
```

This operation binds the socket handle with the port address. You can specify the IP Address as well however using "0" simply allows the driver to bind to any IP Address (the local one). You can also specify "0" for the port address to bind to a random port. However servers generally use a fixed port number since the clients still need to find them but there are exceptions.

Step Three: Listen on the Socket

This will put the socket into a listening state. The socket will be able to listen for connections after this call. The number specified is simply the back log of connections waiting to be accepted that this socket will allow.

```
if(listen(hSocket, 5) != 0)
{
   /* Error */
}
```

Step Four: Accept Connections

The `accept` API will provide you with a new handle for each incoming connection. The following is a code example of using accept.

```
if((hNewClient = accept(pServerInfo->hServerSocket,
      (struct sockaddr *)&NewClientSockAddr, &uiLength)) != INVALID_SOCKET)
{
```

The returned handle can then be used to send and receive data.

Step Five: Close the Socket

When you are done you need to close any and all handles just like anything else!

```
closesocket(hNewClient);
```

There is one extra detail omitted here about the `select` API being used to get notifications when a connection comes and when data is available. This is simply a refresher for further details you should consult a sockets tutorial or API reference like MSDN.

Socket Client Application

The client side of a sockets communications simply connects to a server and then sends/receives data. The following steps break down how to setup this communications.

Step One: Create a Socket

The first step is to create a socket. The following code shows how to create a socket for streaming (TCP/IP).

```
hSocket = socket(PF_INET, SOCK_STREAM, 0);

if(hSocket == INVALID_SOCKET)
{
   /* Error */
}
```

This is then simply a handle to the network driver. You use this handle in other calls to the socket API.

Step Two: Connect to a Server

You need to setup the address and port of the server to connect to and they must be in network byte order. You will then call the `connect` API to establish a connection between the client and server.

```
pClientConnectInfo->SockHostAddress.sin_family = PF_INET;
pClientConnectInfo->SockHostAddress.sin_port   =
                 htons(4000);     /* Network Byte Order! */

printf("Enter Host IP Address like: 127.0.0.1\n");
fgets(szHostName, 100, stdin);

pClientConnectInfo->SockHostAddress.sin_addr.s_addr =
             inet_addr(szHostName);     /* Network Byte Order! */

iRetVal =
  connect(hSocket, (LPSOCKADDR)&pClientConnectInfo->SockHostAddress,
                                             sizeof(SOCKADDR_IN));

if(iRetVal == INVALID_SOCKET)
{
    /* Error */
}
```

Step Three: Send and Receive Data

Once you are connected, you just need to send and receive data whenever you want, using the `recv` and `send` APIs.

```
iRetVal = send(hSocket, szBuffer, strlen(szBuffer), 0);

if(iRetVal == SOCKET_ERROR)
{
  /* Error */
}
...

iRetVal = recv(hSocket, szBuffer, 1000, 0);

if(iRetVal == 0 || iRetVal == SOCKET_ERROR)
{
  /* Error */
}
```

Please note that these examples may refer to sending and receiving strings, however any binary data can be sent.

Step Four: Close the Socket

When you are done you need to close any and all handles just like anything else!

```
closesocket(hSocket);
```

There is one extra detail omitted here about the `select` API used to get notifications when data is available. This is simply a refresher and a lot of details of sockets have been omitted and so for further details you should consult a sockets tutorial or API reference like MSDN.

Transport Device Interface

The sockets primer was really to get you ready for the TDI API. The "Transport Device Interface" is a set of APIs which can be used by a driver to communicate with a Transport (Protocol) Driver such as TCP. The TCP driver would implement this API set so that your driver can communicate to it. This is a little more complex than using sockets and the documentation on MSDN can be more confusing than helpful. So we will go over all the steps needed to make a client side connection. Once you understand this, you should be able to use the API to perform other operations such as creating a server for example.

The Architecture

The following diagram outlines the TDI/NDIS relationship. In general, TDI is a standard interface in which transport/protocol driver developers can implement in their drivers. In this manner developers that wish to use their protocol can implement a standard interface without the hassle of implementing separate interfaces for each protocol they wish to support. This does not mean that those developers are limited to only implementing TDI. They can also implement any proprietary interface that they wish on the top level of their driver. I am not an expert in NDIS, so I will leave these as simple explanations, so I hopefully won't get anything wrong! These are just "good to know" type information anyway and we don't need to understand any of these to use the TDI Client Driver.

The Protocol drivers will talk to the NDIS interface API on the lower end of the driver. The job of the protocol driver is just that, to implement a protocol and talk with NDIS. The upper layer of the driver can be a proprietary interface or TDI or both. By the way, these are NOT "NDIS Clients". They do not exist. There are websites out there that have referred to these drivers as "NDIS Clients" and that's completely wrong. I once asked an NDIS expert about "NDIS Clients" and they didn't know what I was talking about!

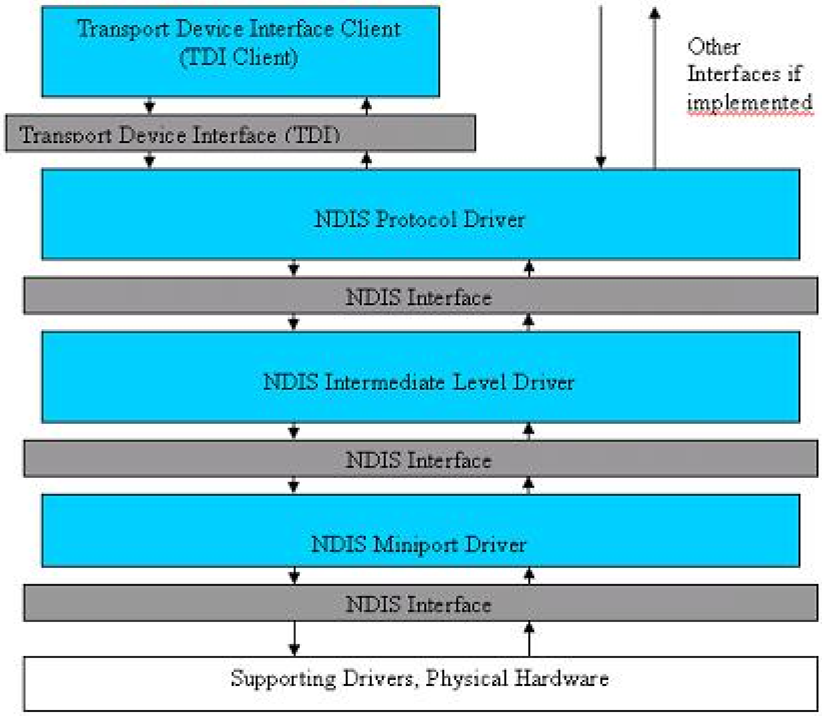
- NDIS Protocol Drivers

  The next layer are the intermediate level drivers. These drivers can do translations, packet scheduling or filtering of data.

- NDIS Intermediate Level Drivers

  The final layer is the NDIS miniport drivers. This essentially talks with the physical NIC device.

- NDIS Miniport Drivers



You can find more information on the TDI and NDIS architectures on MSDN.

Step One: Open a Transport Address

The first step is to create a handle to a "Transport Address". This will require you to use `ZwCreateFile` to create a handle of an instance to a "Transport Address". The "Transport Address" is the IP Address of the LOCAL MACHINE. This is NOT THE REMOTE MACHINE! The reasoning behind letting you bind to a specific IP address is in the instance where multiple IP Addresses are associated with the local machine for example when there are multiple NICs installed. You can also simply specify "0.0.0.0" to grab any random NIC.

The method of opening this handle is a little obscure for those who are not used to developing drivers. You have to specify the "EA" or "Extedned Attributes" which are then passed to the driver via `IRP_MJ_CREATE`! Yes, it is possible to pass parameters into the open aside from adding to the end of the DOS Device Name (As we did in the previous article). You are also able to specify the local port at this time. If you are creating a server this would then be the time to specify the port. Since we are only implementing a client connection we don't care about the port so it's left at 0.

The following code illustrates how to open a Transport Address.

```
NTSTATUS TdiFuncs_OpenTransportAddress(PHANDLE pTdiHandle,
                                       PFILE_OBJECT *pFileObject)
{
    NTSTATUS NtStatus = STATUS_INSUFFICIENT_RESOURCES;
    UNICODE_STRING usTdiDriverNameString;
    OBJECT_ATTRIBUTES oaTdiDriverNameAttributes;
    IO_STATUS_BLOCK IoStatusBlock;
    char DataBlob[sizeof(FILE_FULL_EA_INFORMATION) +
                     TDI_TRANSPORT_ADDRESS_LENGTH + 300] = {0};
    PFILE_FULL_EA_INFORMATION pExtendedAttributesInformation =
         (PFILE_FULL_EA_INFORMATION)&DataBlob;
    UINT dwEASize = 0;
    PTRANSPORT_ADDRESS pTransportAddress = NULL;
    PTDI_ADDRESS_IP pTdiAddressIp = NULL;

    /*
     * Initialize the name of the device to be opened.  ZwCreateFile takes an
```

```
      * OBJECT_ATTRIBUTES structure as the name of the device to open.
      * This is then a two step process.
      *
      *  1 - Create a UNICODE_STRING data structure from a unicode string.
      *  2 - Create a OBJECT_ATTRIBUTES data structure from a UNICODE_STRING.
      *
      */

     RtlInitUnicodeString(&usTdiDriverNameString, L"\\Device\\Tcp");
     InitializeObjectAttributes(&oaTdiDriverNameAttributes,
           &usTdiDriverNameString,
           OBJ_CASE_INSENSITIVE | OBJ_KERNEL_HANDLE,
           NULL, NULL);

     /*
      * The second step is to initialize the Extended Attributes data structure.
      *
      *  EaName        =  TdiTransportAddress, 0, TRANSPORT_ADDRESS
      *  EaNameLength  = Length of TdiTransportAddress
      *  EaValueLength = Length of TRANSPORT_ADDRESS
      */
      RtlCopyMemory(&pExtendedAttributesInformation->EaName,
              TdiTransportAddress,
              TDI_TRANSPORT_ADDRESS_LENGTH);

      pExtendedAttributesInformation->EaNameLength =
                               TDI_TRANSPORT_ADDRESS_LENGTH;
      pExtendedAttributesInformation->EaValueLength =
                               TDI_TRANSPORT_ADDRESS_LENGTH +
               sizeof(TRANSPORT_ADDRESS) +
               sizeof(TDI_ADDRESS_IP);
      pTransportAddress =
         (PTRANSPORT_ADDRESS)(&pExtendedAttributesInformation->EaName +
         TDI_TRANSPORT_ADDRESS_LENGTH + 1);

      /*
       * The number of transport addresses
       */
      pTransportAddress->TAAddressCount = 1;

      /*
       *  This next piece will essentially describe what
       *                                  the transport being opened is.
       * AddressType   =  Type of transport
       * AddressLength =  Length of the address
       * Address =  A data structure that is essentially
       *                        related to the chosen AddressType.
       */

      pTransportAddress->Address[0].AddressType    = TDI_ADDRESS_TYPE_IP;
      pTransportAddress->Address[0].AddressLength  = sizeof(TDI_ADDRESS_IP);
      pTdiAddressIp =
           (TDI_ADDRESS_IP *)&pTransportAddress->Address[0].Address;

      /*
       * The TDI_ADDRESS_IP data structure is essentially simmilar to
       * the usermode sockets data structure.
       *    sin_port
       *    sin_zero
       *    in_addr
       *
       *NOTE: This is the _LOCAL ADDRESS OF THE CURRENT MACHINE_ Just as with
       *     sockets, if you don't care what port you bind this connection to t
       *     hen just use "0". If you also only have one network card interface,
       *     there's no reason to set the IP. "0.0.0.0" will simply use the
```

```
     *     current machine's IP.  If you have multiple NIC's or a reason to
     *     specify the local IP address then you must set TDI_ADDRESS_IP
     *     to that IP.  If you are creating a server side component you may
     *     want to specify the port, however usually to connectto another
     *     server you really don't care what port the client is opening.
     */

     RtlZeroMemory(pTdiAddressIp, sizeof(TDI_ADDRESS_IP));

     dwEASize = sizeof(DataBlob);

     NtStatus = ZwCreateFile(pTdiHandle, FILE_READ_EA | FILE_WRITE_EA,
        &oaTdiDriverNameAttributes,
        &IoStatusBlock, NULL, FILE_ATTRIBUTE_NORMAL, 0, FILE_OPEN_IF, 0,
        pExtendedAttributesInformation, dwEASize);

     if(NT_SUCCESS(NtStatus))
     {
          NtStatus = ObReferenceObjectByHandle(*pTdiHandle,
                         GENERIC_READ | GENERIC_WRITE,
                         NULL,
                         KernelMode,
                         (PVOID *)pFileObject, NULL);

          if(!NT_SUCCESS(NtStatus))
          {
              ZwClose(*pTdiHandle);
          }
     }

     return NtStatus;
}
```

This is described on MSDN.

Step Two: Open a Connection Context

The second step is to open a Connection Context. This is the handle that you will actually be using in all subsequent operations to be performed on this connection. This is also done by `ZwCreateFile` and it is also performed on the same device "\Device\Tcp". This device actually allows you to open three different handles. The three handles transport handle, the connection context and a control handle. A common mistake is to think that a handle open succeeded and it's actually a handle open to the wrong handle! This is because they use the "Extended Attributes" to determine which handle is being opened. Apparently, if the driver doesn't recognize the EA value, it then simply opens the default handle type, "Control"! This is documented in the description of the create on MSDN.

The following code demonstrates opening up a connection context. Note that you can also specify a pointer value called a "`CONNECTION_CONTEXT`" which is just a pointer to user defined data. Later you may notice that some event callbacks will provide this pointer back to you. This is essentially what you can use this context value for.

```
NTSTATUS TdiFuncs_OpenConnection(PHANDLE pTdiHandle, PFILE_OBJECT *pFileObject)
{
    NTSTATUS NtStatus = STATUS_INSUFFICIENT_RESOURCES;
    UNICODE_STRING usTdiDriverNameString;
    OBJECT_ATTRIBUTES oaTdiDriverNameAttributes;
    IO_STATUS_BLOCK IoStatusBlock;
    char DataBlob[sizeof(FILE_FULL_EA_INFORMATION) +
              TDI_CONNECTION_CONTEXT_LENGTH + 300] = {0};
    PFILE_FULL_EA_INFORMATION pExtendedAttributesInformation =
                    (PFILE_FULL_EA_INFORMATION)&DataBlob;
    UINT dwEASize = 0;

    /*
```

```
     * Initialize the name of the device to be opened.  ZwCreateFile
     * takes an OBJECT_ATTRIBUTES structure as the name of the device
     * to open.  This is then a two step process.
     *
     *  1 - Create a UNICODE_STRING data structure from a unicode string.
     *  2 - Create a OBJECT_ATTRIBUTES data structure from a UNICODE_STRING.
     *
     */

    RtlInitUnicodeString(&usTdiDriverNameString, L"\\Device\\Tcp");
    InitializeObjectAttributes(&oaTdiDriverNameAttributes,
            &usTdiDriverNameString,
            OBJ_CASE_INSENSITIVE | OBJ_KERNEL_HANDLE,
            NULL, NULL);

    /*
     * The second step is to initialize the Extended Attributes data structure.
     *
     *  EaName    =  TdiConnectionContext, 0, Your User Defined Context Data
     *                                            (Actually a pointer to it)
     *  EaNameLength  = Length of TdiConnectionContext
     *  EaValueLength = Entire Length
     */
     RtlCopyMemory(&pExtendedAttributesInformation->EaName,
                        TdiConnectionContext, TDI_CONNECTION_CONTEXT_LENGTH);

     pExtendedAttributesInformation->EaNameLength =
                                          TDI_CONNECTION_CONTEXT_LENGTH;
     pExtendedAttributesInformation->EaValueLength =
                                       TDI_CONNECTION_CONTEXT_LENGTH;
              /* Must be at least TDI_CONNECTION_CONTEXT_LENGTH */

     dwEASize = sizeof(DataBlob);

     NtStatus = ZwCreateFile(pTdiHandle,
         FILE_READ_EA | FILE_WRITE_EA, &oaTdiDriverNameAttributes,
         &IoStatusBlock, NULL,
         FILE_ATTRIBUTE_NORMAL, 0, FILE_OPEN_IF, 0,
         pExtendedAttributesInformation, dwEASize);

     if(NT_SUCCESS(NtStatus))
     {
          NtStatus = ObReferenceObjectByHandle(*pTdiHandle,
                          GENERIC_READ | GENERIC_WRITE,
                          NULL, KernelMode,
                         (PVOID *)pFileObject, NULL);

          if(!NT_SUCCESS(NtStatus))
          {
              ZwClose(*pTdiHandle);
          }
     }

     return NtStatus;
}
```

This is described on MSDN.

Step Three: Associate The Transport Address and Connection Context

You need to associate the two handles, the transport and connection, before you can perform any operations. This is done by sending an IOCTL to the the device. If you remember before how to send an IOCTL we need to allocate an IRP, set the parameters and send it to the device. This however is simplified since the TDI header files provide macros and other functions which can do this for you. The

`TdiBuildInternalDeviceControlIrp` is actually a macro for calling `IoBuildDeviceIoControlRequest`. Some of the parameters to this macro are actually ignored but are useful just for comments (such as the supplied IOCTL!). This API is simple and we use it here for demonstration purposes however there are advantages to using other mechanisms for creating IRP's such as `IoAllocateIrp` which will be described later. The other macros that we will be using simply set the parameters of the `IO_STACK_LOCATION` for the next lower driver.

The one thing you may notice different here than what we talked about last time is the "`STATUS_PENDING`". This will be discussed later in this tutorial.

The following code demonstrates how to do this.

```
NTSTATUS TdiFuncs_AssociateTransportAndConnection(HANDLE hTransportAddress,
                                     PFILE_OBJECT pfoConnection)
{
    NTSTATUS NtStatus = STATUS_INSUFFICIENT_RESOURCES;
    PIRP pIrp;
    IO_STATUS_BLOCK IoStatusBlock = {0};
    PDEVICE_OBJECT pTdiDevice;
    TDI_COMPLETION_CONTEXT TdiCompletionContext;

    KeInitializeEvent(&TdiCompletionContext.kCompleteEvent,
                            NotificationEvent, FALSE);

    /*
     * The TDI Device Object is required to send these
     *                  requests to the TDI Driver.
     */

    pTdiDevice = IoGetRelatedDeviceObject(pfoConnection);

    /*
     * Step 1: Build the IRP.  TDI defines several macros and functions
     *         that can quickly create IRP's, etc. for variuos purposes.
     *          While this can be done manually it's easiest to use the macros.
     *
     *  http://msdn.microsoft.com/library/en-us/network/hh/network/
     *        34bldmac_f430860a-9ae2-4379-bffc-6b0a81092e7c.xml.asp?frame=true
     */
    pIrp = TdiBuildInternalDeviceControlIrp(TDI_ASSOCIATE_ADDRESS,
          pTdiDevice, pfoConnection, &TdiCompletionContext.kCompleteEvent,
          &IoStatusBlock);

    if(pIrp)
    {
        /*
         * Step 2: Add the correct parameters into the IRP.
         */
        TdiBuildAssociateAddress(pIrp, pTdiDevice,
                            pfoConnection, NULL, NULL, hTransportAddress);

        NtStatus = IoCallDriver(pTdiDevice, pIrp);

        /*
         *  If the status returned is STATUS_PENDING this means that the IRP
         *  will not be completed synchronously and the driver has queued the
         *  IRP for later processing.  This is fine but we do not want
         *  to return this thread, we are a synchronous call so we want
         *  to wait until it has completed. The EVENT that we provided will
         *  be set when the IRP completes.
         */

        if(NtStatus == STATUS_PENDING)
```

```
        {
            KeWaitForSingleObject(&TdiCompletionContext.kCompleteEvent,
                                  Executive, KernelMode, FALSE, NULL);
            /*
             * Find the Status of the completed IRP
             */

            NtStatus = IoStatusBlock.Status;
        }

    }

    return NtStatus;
}
```

This is described on MSDN.

Step Four: Connect

To create the client side of a TCP connection, we need to connect!

```
NTSTATUS TdiFuncs_Connect(PFILE_OBJECT pfoConnection,
                                UINT uiAddress, USHORT uiPort)
{
    NTSTATUS NtStatus = STATUS_INSUFFICIENT_RESOURCES;
    PIRP pIrp;
    IO_STATUS_BLOCK IoStatusBlock = {0};
    PDEVICE_OBJECT pTdiDevice;
    TDI_CONNECTION_INFORMATION  RequestConnectionInfo = {0};
    TDI_CONNECTION_INFORMATION  ReturnConnectionInfo  = {0};
    LARGE_INTEGER TimeOut = {0};
    UINT NumberOfSeconds = 60*3;
    char cBuffer[256] = {0};
    PTRANSPORT_ADDRESS pTransportAddress =(PTRANSPORT_ADDRESS)&cBuffer;
    PTDI_ADDRESS_IP pTdiAddressIp;
    TDI_COMPLETION_CONTEXT TdiCompletionContext;

    KeInitializeEvent(&TdiCompletionContext.kCompleteEvent,
                                NotificationEvent, FALSE);

    /*
     * The TDI Device Object is required to send these
     *                  requests to the TDI Driver.
     */

    pTdiDevice = IoGetRelatedDeviceObject(pfoConnection);

    /*
     * Step 1: Build the IRP.  TDI defines several macros and functions
     *     that can quickly create IRP's, etc. for variuos purposes.
     *     While this can be done manually it's easiest to use the macros.
     *
     *  http://msdn.microsoft.com/library/en-us/network/hh/network/
     *   34bldmac_f430860a-9ae2-4379-bffc-6b0a81092e7c.xml.asp?frame=true
     */
    pIrp = TdiBuildInternalDeviceControlIrp(TDI_CONNECT, pTdiDevice,
               pfoConnection, &TdiCompletionContext.kCompleteEvent,
               &IoStatusBlock);

    if(pIrp)
    {
```

```
        /*
         * Step 2: Add the correct parameters into the IRP.
         */

        /*
         *  Time out value
         */

        TimeOut.QuadPart = 10000000L;
        TimeOut.QuadPart *= NumberOfSeconds;
        TimeOut.QuadPart = -(TimeOut.QuadPart);

        /*
         * Initialize the RequestConnectionInfo which specifies
         * the address of the REMOTE computer
         */

        RequestConnectionInfo.RemoteAddress       = (PVOID)pTransportAddress;
        RequestConnectionInfo.RemoteAddressLength =
                      sizeof(PTRANSPORT_ADDRESS) + sizeof(TDI_ADDRESS_IP);

         /*
          * The number of transport addresses
          */
         pTransportAddress->TAAddressCount = 1;

         /*
          *  This next piece will essentially describe what the
          *                            transport being opened is.
          *     AddressType   =  Type of transport
          *     AddressLength =  Length of the address
          *     Address       =  A data structure that is essentially
          *                      related to the chosen AddressType.
          */

         pTransportAddress->Address[0].AddressType    =
                                              TDI_ADDRESS_TYPE_IP;
         pTransportAddress->Address[0].AddressLength  =
                                              sizeof(TDI_ADDRESS_IP);
         pTdiAddressIp =
             (TDI_ADDRESS_IP *)&pTransportAddress->Address[0].Address;

         /*
          * The TDI_ADDRESS_IP data structure is essentially simmilar
          *                to the usermode sockets data structure.
          *    sin_port
          *    sin_zero
          *    in_addr
          */

        /*
         *  Remember, these must be in NETWORK BYTE ORDER (Big Endian)
         */

        /* Example: 1494 = 0x05D6 (Little Endian) or 0xD605 (Big Endian)*/

        pTdiAddressIp->sin_port = uiPort;

        /* Example: 10.60.2.159 = 0A.3C.02.9F (Little Endian)
           or 9F.02.3C.0A (Big Endian)
        */
        pTdiAddressIp->in_addr  = uiAddress;

        TdiBuildConnect(pIrp, pTdiDevice, pfoConnection, NULL, NULL,
              &TimeOut, &RequestConnectionInfo,
```

```
                &ReturnConnectionInfo);

        NtStatus = IoCallDriver(pTdiDevice, pIrp);

        /*
         *  If the status returned is STATUS_PENDING this means
         *  that the IRP will not  be completed synchronously
         *  and the driver has queued the IRP for later processing.
         *  This is fine but we do not want to return this thread,
         *  we are a synchronous call so we want to wait until
         *  it has completed.  The EVENT that we provided will be
         *  set when the IRP completes.
         */

        if(NtStatus == STATUS_PENDING)
        {
            KeWaitForSingleObject(&TdiCompletionContext.kCompleteEvent,
                                  Executive, KernelMode, FALSE, NULL);

            /*
             * Find the Status of the completed IRP
             */

            NtStatus = IoStatusBlock.Status;
        }

    }

    return NtStatus;
}
```

This is described on MSDN.

Step Five: Send and Receive Data

To send data you simply create a `TDI_SEND IOCTL` and pass it to the transport device. The following code implements the send:

```
NTSTATUS TdiFuncs_Send(PFILE_OBJECT pfoConnection, PVOID pData,
                                UINT uiSendLength, UINT *pDataSent)
{
    NTSTATUS NtStatus = STATUS_INSUFFICIENT_RESOURCES;
    PIRP pIrp;
    IO_STATUS_BLOCK IoStatusBlock = {0};
    PDEVICE_OBJECT pTdiDevice;
    PMDL pSendMdl;
    TDI_COMPLETION_CONTEXT TdiCompletionContext;

    KeInitializeEvent(&TdiCompletionContext.kCompleteEvent,
                                          NotificationEvent, FALSE);

    /*
     * The TDI Device Object is required to
     *               send these requests to the TDI Driver.
     */

    pTdiDevice = IoGetRelatedDeviceObject(pfoConnection);

    *pDataSent = 0;

    /*
     *  The send requires an MDL which is what you may remember from DIRECT_IO.
```

```
     *  However, instead of using an MDL we need to create one.
     */
    pSendMdl = IoAllocateMdl((PCHAR )pData, uiSendLength, FALSE, FALSE, NULL);

    if(pSendMdl)
    {

        __try {

            MmProbeAndLockPages(pSendMdl, KernelMode, IoModifyAccess);

        } __except (EXCEPTION_EXECUTE_HANDLER) {
                IoFreeMdl(pSendMdl);
                pSendMdl = NULL;
        };

        if(pSendMdl)
        {

            /*
             * Step 1: Build the IRP.  TDI defines several macros and functions
             *         that can quickly create IRP's, etc. for variuos purposes.
             *         While this can be done manually it's easiest to use
             *         the macros.
             */
            pIrp = TdiBuildInternalDeviceControlIrp(TDI_SEND,
                     pTdiDevice, pfoConnection,
                     &TdiCompletionContext.kCompleteEvent,
                     &IoStatusBlock);

            if(pIrp)
            {
                /*
                 * Step 2: Add the correct parameters into the IRP.
                 */


                TdiBuildSend(pIrp, pTdiDevice, pfoConnection, NULL,
                                       NULL, pSendMdl, 0, uiSendLength);

                NtStatus = IoCallDriver(pTdiDevice, pIrp);

                /*
                 *  If the status returned is STATUS_PENDING this means that the
                 *  IRP will not be completed synchronously and the driver has
                 *  queued the IRP for later processing.  This is fine but we do
                 *  not want to return this not want to return this not want to
                 *  return this to wait until it has completed.  The EVENT
                 *  that we providedwill be set when the IRP completes.
                 */

                if(NtStatus == STATUS_PENDING)
                {
                    KeWaitForSingleObject(&TdiCompletionContext.kCompleteEvent,
                                           Executive, KernelMode, FALSE, NULL);

                }

                NtStatus   = IoStatusBlock.Status;
                *pDataSent = (UINT)IoStatusBlock.Information;

               /*
                * I/O Manager will free the MDL
                *
                if(pSendMdl)
```

```
                {
                    MmUnlockPages(pSendMdl);
                    IoFreeMdl(pSendMdl);
                } */

            }
        }
    }

    return NtStatus;
}
```

The same can be done for receive using the `TDI_RECIEVE` however our implementation does not use this. If you notice, you can actually create notification callbacks to tell you when there is data or other events. This is what we have done and the API wrapper that I implemented to create any event handler is as follows:

```
NTSTATUS TdiFuncs_SetEventHandler(PFILE_OBJECT pfoTdiFileObject,
            LONG InEventType, PVOID InEventHandler, PVOID InEventContext)
{
    NTSTATUS NtStatus = STATUS_INSUFFICIENT_RESOURCES;
    PIRP pIrp;
    IO_STATUS_BLOCK IoStatusBlock = {0};
    PDEVICE_OBJECT pTdiDevice;
    LARGE_INTEGER TimeOut = {0};
    UINT NumberOfSeconds = 60*3;
    TDI_COMPLETION_CONTEXT TdiCompletionContext;

    KeInitializeEvent(&TdiCompletionContext.kCompleteEvent,
                           NotificationEvent, FALSE);

    /*
     * The TDI Device Object is required to send these
     *                      requests to the TDI Driver.
     */

    pTdiDevice = IoGetRelatedDeviceObject(pfoTdiFileObject);

    /*
     * Step 1: Build the IRP.  TDI defines several macros and functions
     *         that can quickly create IRP's, etc. for variuos purposes.
     *         While this can be done manually it's easiest to use the macros.
     *
     */
    pIrp = TdiBuildInternalDeviceControlIrp(TDI_SET_EVENT_HANDLER,
            pTdiDevice, pfoConnection, &TdiCompletionContext.kCompleteEvent,
            &IoStatusBlock);

    if(pIrp)
    {
        /*
         * Step 2: Set the IRP Parameters
         */

        TdiBuildSetEventHandler(pIrp, pTdiDevice, pfoTdiFileObject,
                NULL, NULL, InEventType, InEventHandler, InEventContext);

        NtStatus = IoCallDriver(pTdiDevice, pIrp);

        /*
         *  If the status returned is STATUS_PENDING this means that
         *  the IRP will not be completed synchronously and the driver has
         *  queued the IRP for later processing.  This is fine but we do not
```

```
         *  want to return this thread, we are a synchronous call so we want
         *  to wait until it has completed.  The EVENT that we provided
         *  will be set when the IRP completes.
         */

        if(NtStatus == STATUS_PENDING)
        {
            KeWaitForSingleObject(&TdiCompletionContext.kCompleteEvent,
                                    Executive, KernelMode, FALSE, NULL);

            /*
             * Find the Status of the completed IRP
             */

            NtStatus = IoStatusBlock.Status;
        }

    }

    return NtStatus;
}
```

The code which uses this API and implements the callback are as follows:

```
  NtStatus = TdiFuncs_SetEventHandler(
                  pTdiExampleContext->TdiHandle.pfoTransport,
                  TDI_EVENT_RECEIVE,
                  TdiExample_ClientEventReceive,
                  (PVOID)pTdiExampleContext);

  ...

NTSTATUS TdiExample_ClientEventReceive(PVOID TdiEventContext,
                         CONNECTION_CONTEXT ConnectionContext,
                         ULONG ReceiveFlags,
                         ULONG  BytesIndicated,
                         ULONG  BytesAvailable,
                         ULONG  *BytesTaken,
                         PVOID  Tsdu,
                         PIRP  *IoRequestPacket)
{
    NTSTATUS NtStatus = STATUS_SUCCESS;
    UINT uiDataRead = 0;
    PTDI_EXAMPLE_CONTEXT pTdiExampleContext =
                        (PTDI_EXAMPLE_CONTEXT)TdiEventContext;
    PIRP pIrp;

    DbgPrint("TdiExample_ClientEventReceive 0x%0x, %i, %i\n",
                  ReceiveFlags, BytesIndicated, BytesAvailable);


    *BytesTaken = BytesAvailable;

    /*
     * This implementation is extremely simple.  We do not queue
     * data if we do not have an IRP to put it there.  We also
     * assume we always get the full data packet sent every recieve.
     * These are Bells and Whistles that can easily be added to
     * any implementation but would help to make the implementation
     * more complex and harder to follow the underlying idea.  Since
     * those essentially are common-sense add ons they are ignored and
     * the general implementation of how to Queue IRP's and
```

```
     * recieve data are implemented.
     *
     */

    pIrp = HandleIrp_RemoveNextIrp(pTdiExampleContext->pReadIrpListHead);

    if(pIrp)
    {
        PIO_STACK_LOCATION pIoStackLocation =
                              IoGetCurrentIrpStackLocation(pIrp);

        uiDataRead =
               BytesAvailable > pIoStackLocation->Parameters.Read.Length ?
               pIoStackLocation->Parameters.Read.Length : BytesAvailable;

        pIrp->Tail.Overlay.DriverContext[0] = NULL;

        RtlCopyMemory(pIrp->AssociatedIrp.SystemBuffer, Tsdu, uiDataRead);

        pIrp->IoStatus.Status      = NtStatus;
        pIrp->IoStatus.Information = uiDataRead;

        IoCompleteRequest(pIrp, IO_NETWORK_INCREMENT);
    }

    /*
     * The I/O Request can be used to recieve the rest of the data.
     * We are not using it in this example however and will actually
     *  be assuming that we always get all the data.
     *
     */
    *IoRequestPacket = NULL;

    return NtStatus;
}
```

Don't get scared with the `HandleIrp_RemoveNextIrp`. we will actually be describing how to queue IRP requests later in this article.

This is described on MSDN.

Step Six: Disconnect

This is nothing special you just disconnect the connection by implementing the `TDI_DISCONNECT IOCTL`.

```
NTSTATUS TdiFuncs_Disconnect(PFILE_OBJECT pfoConnection)
{
    NTSTATUS NtStatus = STATUS_INSUFFICIENT_RESOURCES;
    PIRP pIrp;
    IO_STATUS_BLOCK IoStatusBlock = {0};
    PDEVICE_OBJECT pTdiDevice;
    TDI_CONNECTION_INFORMATION  ReturnConnectionInfo  = {0};
    LARGE_INTEGER TimeOut = {0};
    UINT NumberOfSeconds = 60*3;
    TDI_COMPLETION_CONTEXT TdiCompletionContext;

    KeInitializeEvent(&TdiCompletionContext.kCompleteEvent,
                                NotificationEvent, FALSE);

    /*
     * The TDI Device Object is required to send
```

```
     *                        these requests to the TDI Driver.
     */

    pTdiDevice = IoGetRelatedDeviceObject(pfoConnection);

    /*
     * Step 1: Build the IRP.  TDI defines several macros and functions
     *         that can quickly create IRP's, etc. for variuos purposes.
     *         While this can be done manually it's easiest to use the macros.
     *
     */
    pIrp = TdiBuildInternalDeviceControlIrp(TDI_DISCONNECT, pTdiDevice,
                  pfoConnection, &TdiCompletionContext.kCompleteEvent,
                  &IoStatusBlock);

    if(pIrp)
    {
        /*
         * Step 2: Add the correct parameters into the IRP.
         */

        /*
         *  Time out value
         */

        TimeOut.QuadPart = 10000000L;
        TimeOut.QuadPart *= NumberOfSeconds;
        TimeOut.QuadPart = -(TimeOut.QuadPart);


        TdiBuildDisconnect(pIrp, pTdiDevice, pfoConnection, NULL, NULL,
                           &TimeOut, TDI_DISCONNECT_ABORT, NULL,
                           &ReturnConnectionInfo);

        NtStatus = IoCallDriver(pTdiDevice, pIrp);

        /*
         *  If the status returned is STATUS_PENDING this means that the
         *  IRP will not be completed synchronously and the driver has
         *  queued the IRP for later processing.  This is fine but we do
         *  not want to return this thread, we are a synchronous call so
         *  we want to wait until it has completed.  The EVENT that
         *  we provided will be set when the IRP completes.
         */

        if(NtStatus == STATUS_PENDING)
        {
            KeWaitForSingleObject(&TdiCompletionContext.kCompleteEvent,
                                  Executive, KernelMode, FALSE, NULL);

            /*
             * Find the Status of the completed IRP
             */

            NtStatus = IoStatusBlock.Status;
        }


    }

    return NtStatus;
}
```

This is described on MSDN.

Step Seven: Disassociate the Handles

This is very simple, we just implement another IOCTL call as follows.

```
NTSTATUS TdiFuncs_DisAssociateTransportAndConnection(PFILE_OBJECT pfoConnection)
{
    NTSTATUS NtStatus = STATUS_INSUFFICIENT_RESOURCES;
    PIRP pIrp;
    IO_STATUS_BLOCK IoStatusBlock = {0};
    PDEVICE_OBJECT pTdiDevice;
    TDI_COMPLETION_CONTEXT TdiCompletionContext;

    KeInitializeEvent(&TdiCompletionContext.kCompleteEvent,
                              NotificationEvent, FALSE);


    /*
     * The TDI Device Object is required to send these requests to the TDI Driver.
     *
     */

    pTdiDevice = IoGetRelatedDeviceObject(pfoConnection);

    /*
     * Step 1: Build the IRP.  TDI defines several macros and
     *         functions that can quickly create IRP's, etc. for
     *         variuos purposes.  While this can be done manually
     *         it's easiest to use the macros.
     *
     */
    pIrp = TdiBuildInternalDeviceControlIrp(TDI_DISASSOCIATE_ADDRESS,
             pTdiDevice, pfoConnection,
             &TdiCompletionContext.kCompleteEvent, &IoStatusBlock);

    if(pIrp)
    {
        /*
         * Step 2: Add the correct parameters into the IRP.
         */
        TdiBuildDisassociateAddress(pIrp, pTdiDevice,
                        pfoConnection, NULL, NULL);

        NtStatus = IoCallDriver(pTdiDevice, pIrp);

        /*
         *  If the status returned is STATUS_PENDING this means that the
         *  IRP will not be completed synchronously and the driver has
         *  queued the IRP for later processing.  This is fine but we
         *  do not want to return this thread, we are a synchronous call
         *  so we want to wait until it has completed. The EVENT that we
         *  provided will be set when the IRP completes.
         */

        if(NtStatus == STATUS_PENDING)
        {
            KeWaitForSingleObject(&TdiCompletionContext.kCompleteEvent,
                                 Executive, KernelMode, FALSE, NULL);

            /*
             * Find the Status of the completed IRP
             */
```

```
            NtStatus = IoStatusBlock.Status;
        }

    }

    return NtStatus;
}
```

This is described on MSDN.

Step Eight: Close the Handles

This function is called on both handles, the Transport and the Connection Context.

```
NTSTATUS TdiFuncs_CloseTdiOpenHandle(HANDLE hTdiHandle,
                                  PFILE_OBJECT pfoTdiFileObject)
{
    NTSTATUS NtStatus = STATUS_SUCCESS;

    /*
     * De-Reference the FILE_OBJECT and Close The Handle
     */

    ObDereferenceObject(pfoTdiFileObject);
    ZwClose(hTdiHandle);

    return NtStatus;
}
```

This is described on MSDN.

Other Resources

The TDI Interface will get a bit easier once you get familiar with it. One of the biggest things to get right when writing any driver is your IRP handling. TDI does seem a little bit more complex than sockets but it is a kernel interface.

If you have ever investigated TDI or NDIS you have probably run into Thomas Divine. If you are looking to purchase complex TDI or NDIS examples, you can find them and other resources on the website of his company. You can also find tutorials of his on various other websites.

IRP Handling

The last article touched on some very basic concepts of IRPs and how to handle them. To keep that article simple, there are actually large gaps in what was described. So in this article we will pick up the pace and attempt to fill in as many of those gaps as we can. You should have a decent bit of exposure to driver development at this time that we should be able to do this quite easily however it will be a lot of information and not all of it is in the example code. You will need to experiment with IRP handling yourself. It is the essential part of developing a driver.

Driver Requests

When writing a driver there are two different times that you will be exposed to IRPs. These are IRPs that are requested to your driver and IRPs that you create to request processing from other drivers. As we remember, there is a stack of drivers and each driver in the stack has their own stack location in the IRP. Each time an IRP is sent down the stack the current stack location of that IRP is advanced. When it comes to your driver you have a few choices.

Forward and Forget

You can forward the IRP to the next driver in the stack using `IoCallDriver`. This is what we did in the other driver tutorial. We forwarded the IRP on and forgot about it. There was one problem though, we didn't take into about `STATUS_PENDING`. `STATUS_PENDING` is a method of implementing asynchronous operations. The lower level driver is notifying the caller that they are not finished with the IRP. They may also be completing this IRP on a separate thread. The rule is that if you return `STATUS_PENDING`, you must also call `IoMarkIrpPending` before returning. This is now a problem though if you have forwarded the IRP to the next driver. You are not allowed to touch it after the call! So you have essentially two choices.

```
IoMarkIrpPending(Irp);
IoCallDriver(pDeviceObject, Irp);

return STATUS_PENDING;
```

The second choice would be to set a completion routine. We should remember those from the code in part 4 however we used them then to simply stop the IRP from completing by returning `STATUS_MORE_PROCESSING_REQUIRED` instead of `STATUS_SUCCESS`.

```
IoSetCompletionRoutine(Irp, CompletionRoutine, NULL, TRUE, TRUE, TRUE);

return IoCallDriver(pDeviceObject, Irp);

...

NTSTATUS CompletionRoutine(PDEVICE_OBJECT DeviceObject,
                           PIRP Irp, PVOID Context)
{
   if(Irp->PendingReturned)
   {
     IoMarkIrpPending(Irp);
   }

   return STATUS_SUCCESS;
}
```

You could again stop the processing here and if you did, you would not need to do `IoMarkIrpPending`. There is circular logic here, if you call `IoMarkIrpPending` then you must return `STATUS_PENDING` from your driver. If you return `STATUS_PENDING` from your driver then you must call `IoMarkIrpPending`. Remember though if you stop processing of a completion, it means that you must then complete it! We did this in part 4.

One thing to note is, it's possible that if a completion routine isn't supplied, that the I/O Manager may be nice enough to propagate this "IoMarkIrpPending" information for you. However information is so scattered on this subject that you may not want to trust that and just make sure everything you do is correct.

Forward and Post Process

This is what we actually did in Part 4 with a slight difference. We need to take into account the pending architecture and if the IRP returns pending from the lower level driver, we need to wait until the lower level driver completes it. Once the driver has completed it we need to wake up our original thread so that we can do processing and complete the IRP. As an optimization, we only want to set the event if pending was returned. There is no reason to add overhead of setting and waiting on events if everything is being processed synchronously! The following is a code example of this.

```
IoSetCompletionRoutine(Irp, CompletionRoutine,
                  &kCompleteEvent, TRUE, TRUE, TRUE);

   NtStatus = IoCallDriver(pDeviceObject, Irp);


   if(NtStatus == STATUS_PENDING)
   {
        KeWaitForSingleObject(&kCompleteEvent,
                     Executive, KernelMode, FALSE, NULL);

        /*
         * Find the Status of the completed IRP
         */

       NtStatus = IoStatusBlock.Status;
   }

   /*
    * Do Post Processing
    */

   IoCompleteRequest(pIrp, IO_NO_INCREMENT);

   return NtStatus;

   ...

   NTSTATUS CompletionRoutine(PDEVICE_OBJECT DeviceObject,
                                    PIRP Irp, PVOID Context)
   {
      if(Irp->PendingReturned)
      {
         KeSetEvent(Context, IO_NO_INCREMENT, FALSE);
      }

      return STATUS_MORE_PROCESSING_REQUIRED;
   }
```

Queue and Pend

You have the option to queue the IRP and process it at a later time or on another thread. This is allowed since you own the IRP while it is at your driver stack level. You have to take into account that the IRP can be canceled. The problem is that if the IRP is canceled, you really don't want to perform any processing since the result will be thrown away. The other problem we want to solve is that, if there are active IRPs associated with a process or thread that process or thread cannot be completely terminated until all active IRPs have been completed. This is very tricky and documentation on how to do this is scarce. However we will show you how to do it here.

Grab your lock

The first thing you need to do is acquire your spinlock that protects your IRP list. This will help synchronize the execution between your queuing logic and your cancel routine. There is a system cancel spinlock that can also be acquired and in some cases it needs to be if you are using certain system provided queuing mechanisms. However since the cancel spinlock is system wide, what do you think is more likely? That another processor would grab your spinlock or that it would grab the cancel spinlock? Most likely it would end up grabbing the cancel spinlock and this can be a performance hit. On a single processor machine, it obviously doesn't matter which one you use but you should attempt to implement your own spinlock.

Set a Cancel Routine

Your cancel routine will also need to grab your spinlock to synchronize execution and remove IRPs from the list. Setting a cancel routine makes sure that if this IRP is canceled, then you know about it and can remove it from your IRP list. Remember, you STILL MUST

COMPLETE THE IRP! There's no way around it. If an IRP is canceled it just doesn't disappear from out under your feet. If it did then while you processed the IRP, if it was canceled, you'd be in big trouble! The purpose of the cancel routine is just while it is in the queue it can be removed from the queue at any time if it's canceled without any hassle.

Check Cancel Flag

You then must check the cancel flag of the IRP. If it is not canceled then you will call `IoMarkIrpPending` and queue the IRP onto your linked list or whatever you have. You then must make sure that you return `STATUS_PENDING` from your driver.

If it has been canceled we need to know if it called your cancel routine. You do this by setting the cancel routine to `NULL`. If the return value is `NULL` then your cancel routine was called. If the return value is not `NULL` then the cancel routine was not called. That just means it was canceled before you set the cancel routine.

You now have two choices remember that only one location can complete the IRP. If the cancel routine was called then as long as the cancel routine doesn't complete the IRP, if it's not in your IRP list, then you can free it. If the cancel routine always completes it, then you must not complete it. If the cancel routine was not called then you obviously must complete it. No matter what happens you must remember two things. The first is that somewhere in your driver you must complete this IRP. The second thing to remember is that you must never complete it twice!

When you remove an IRP from the list it's the same thing. You should always check to make sure the IRP has not been canceled. You will also set the cancel routine to `NULL` before removing the IRP to process it. That way even if it is canceled now you don't care, the result will just be thrown away. The best thing to do now is just to see the code.

```
Irp->Tail.Overlay.DriverContext[0] =
         (PVOID)pTdiExampleContext->pWriteIrpListHead;
NtStatus = HandleIrp_AddIrp(pTdiExampleContext->pWriteIrpListHead,
         Irp, TdiExample_CancelRoutine, TdiExample_IrpCleanUp, NULL);

if(NT_SUCCESS(NtStatus))
{
    KeSetEvent(&pTdiExampleContext->kWriteIrpReady,
                              IO_NO_INCREMENT, FALSE);
    NtStatus = STATUS_PENDING;
}
...

/**********************************************************************
 *
 *  HandleIrp_AddIrp
 *
 *    This function adds an IRP to the IRP List.
 *
 **********************************************************************/
NTSTATUS HandleIrp_AddIrp(PIRPLISTHEAD pIrpListHead,
                          PIRP pIrp,
                          PDRIVER_CANCEL pDriverCancelRoutine,
                          PFNCLEANUPIRP pfnCleanUpIrp,
                          PVOID pContext)
{
    NTSTATUS NtStatus = STATUS_UNSUCCESSFUL;
    KIRQL kOldIrql;
    PDRIVER_CANCEL pCancelRoutine;
    PIRPLIST pIrpList;

    pIrpList = (PIRPLIST)KMem_AllocateNonPagedMemory(sizeof(IRPLIST),
                                            pIrpListHead->ulPoolTag);

    if(pIrpList)
    {
        DbgPrint("HandleIrp_AddIrp Allocate Memory = 0x%0x \r\n", pIrpList);
```

```
    pIrpList->pContext      = pContext;
    pIrpList->pfnCleanUpIrp = pfnCleanUpIrp;
    pIrpList->pIrp          = pIrp;
    pIrpList->pfnCancelRoutine = pDriverCancelRoutine;

    /*
     *  The first thing we need to to is acquire our spin lock.
     *
     *  The reason for this is a few things.
     *
     *     1. All access to this list is synchronized, the obvious reason
     *     2. This will synchronize adding this IRP to the
     *             list with the cancel routine.
     */

    KeAcquireSpinLock(&pIrpListHead->kspIrpListLock, &kOldIrql);

    /*
     * We will now attempt to set the cancel routine which will be called
     * when (if) the IRP is ever canceled.  This allows us to remove an IRP
     * from the queue that is no longer valid.
     *
     * A potential misconception is that if the IRP is canceled it is no
     * longer valid.  This is not true the IRP does not self-destruct.
     * The IRP is valid as long as it has not been completed.  Once it
     * has been completed this is when it is no longer valid (while we
     * own it).  So, while we own the IRP we need to complete it at some
     * point.  The reason for setting a cancel routine is to realize
     * that the IRP has been canceled and complete it immediately and
     * get rid of it. We don't want to do processing for an IRP that
     * has been canceled as the result will just be thrown away.
     *
     * So, if we remove an IRP from this list for processing and
     * it's canceled the only problem is that we did processing on it.
     * We complete it at the end and there's no problem.
     *
     * There is a problem however if your code is written in a way
     * that allows your cancel routine to complete the IRP unconditionally.
     * This is fine as long as you have some type of synchronization
     * since you DO NOT WANT TO COMPLETE AN IRP TWICE!!!!!!
     */

    IoSetCancelRoutine(pIrp, pIrpList->pfnCancelRoutine);

    /*
     * We have set our cancel routine.  Now, check if the IRP has
     *                         already been canceled.
     * We must set the cancel routine before checking this to ensure
     * that once we queue the IRP it will definately be called if the
     * IRP is ever canceled.
     */

    if(pIrp->Cancel)
    {
        /*
         * If the IRP has been canceled we can then check if our
         * cancel routine has been called.
         */
        pCancelRoutine = IoSetCancelRoutine(pIrp, NULL);

        /*
         * if pCancelRoutine ==
         *               NULL then our cancel routine has been called.
         * if pCancelRoutine !=
         *                NULL then our cancel routine has not been called.
```

```
             *
             * The I/O Manager will set the cancel routine to NULL
             * before calling the cancel routine.
             * We have a decision to make here, we need to write the code
             * in a way that we only complete and clean up the IRP once.
             * We either allow the cancel routine to do it or we do it here.
             * Now, we will already have to clean up the IRP here if the
             * pCancelRoutine != NULL.
             *
             * The solution we are going with here is that we will only clean
             *  up IRP's in the cancel routine if the are in the list.
             * So, we will not add any IRP to the list if it has
             * already been canceled once we get to this location.
             *
             */
            KeReleaseSpinLock(&pIrpListHead->kspIrpListLock, kOldIrql);

            /*
             * We are going to allow the clean up function to complete the IRP.
             */
            pfnCleanUpIrp(pIrp, pContext);
            DbgPrint("HandleIrp_AddIrp Complete Free Memory = 0x%0x \r\n",
                                                              pIrpList);
            KMem_FreeNonPagedMemory(pIrpList);
        }
        else
        {
            /*
             * The IRP has not been canceled, so we can simply queue it!
             */


            pIrpList->pNextIrp      = NULL;

            IoMarkIrpPending(pIrp);

            if(pIrpListHead->pListBack)
            {
               pIrpListHead->pListBack->pNextIrp = pIrpList;
               pIrpListHead->pListBack           = pIrpList;
            }
            else
            {
               pIrpListHead->pListFront = pIrpListHead->pListBack =
                                                                pIrpList;
            }

            KeReleaseSpinLock(&pIrpListHead->kspIrpListLock,
                                                              kOldIrql);

            NtStatus = STATUS_SUCCESS;
        }
    }
    else
    {
        /*
         * We are going to allow the clean up function to complete the IRP.
         */
        pfnCleanUpIrp(pIrp, pContext);
    }


    return NtStatus;
}
```

```
/**********************************************************************
 *
 *  HandleIrp_RemoveNextIrp
 *
 *    This function removes the next valid IRP.
 *
 **********************************************************************/
PIRP HandleIrp_RemoveNextIrp(PIRPLISTHEAD pIrpListHead)
{
    PIRP pIrp = NULL;
    KIRQL kOldIrql;
    PDRIVER_CANCEL pCancelRoutine;
    PIRPLIST pIrpListCurrent;

    KeAcquireSpinLock(&pIrpListHead->kspIrpListLock, &kOldIrql);

    pIrpListCurrent  = pIrpListHead->pListFront;

    while(pIrpListCurrent && pIrp == NULL)
    {
        /*
         * To remove an IRP from the Queue we first want to
         * reset the cancel routine.
         */
        pCancelRoutine = IoSetCancelRoutine(pIrpListCurrent->pIrp, NULL);

        /*
         * The next phase is to determine if this IRP has been canceled
         */

        if(pIrpListCurrent->pIrp->Cancel)
        {
            /*
             * We have been canceled so we need to determine if our
             * cancel routine has already been called.  pCancelRoutine
             * will be NULL if our cancel routine has been called.
             * If will not be NULL if our cancel routine has not been
             * called.  However, we don't care in either case and we
             * will simply complete the IRP here since we have to implement at
             * least that case anyway.
             *
             * Remove the IRP from the list.
             */

            pIrpListHead->pListFront = pIrpListCurrent->pNextIrp;

            if(pIrpListHead->pListFront == NULL)
            {
                pIrpListHead->pListBack = NULL;
            }

            KeReleaseSpinLock(&pIrpListHead->kspIrpListLock, kOldIrql);

            pIrpListCurrent->pfnCleanUpIrp(pIrpListCurrent->pIrp,
                                        pIrpListCurrent->pContext);

            DbgPrint("HandleIrp_RemoveNextIrp Complete Free Memory =
                                           0x%0x \r\n", pIrpListCurrent);
            KMem_FreeNonPagedMemory(pIrpListCurrent);
            pIrpListCurrent = NULL;

            KeAcquireSpinLock(&pIrpListHead->kspIrpListLock,
                                                   &kOldIrql);

            pIrpListCurrent  = pIrpListHead->pListFront;
```

```
        }
        else
        {
            pIrpListHead->pListFront = pIrpListCurrent->pNextIrp;

            if(pIrpListHead->pListFront == NULL)
            {
                pIrpListHead->pListBack = NULL;
            }

            pIrp = pIrpListCurrent->pIrp;

            KeReleaseSpinLock(&pIrpListHead->kspIrpListLock, kOldIrql);

            DbgPrint("HandleIrp_RemoveNextIrp Complete Free Memory = 0x%0x \r\n",
                                                              pIrpListCurrent);
            KMem_FreeNonPagedMemory(pIrpListCurrent);
            pIrpListCurrent = NULL;

            KeAcquireSpinLock(&pIrpListHead->kspIrpListLock,
                                                          &kOldIrql);

        }
    }


    KeReleaseSpinLock(&pIrpListHead->kspIrpListLock, kOldIrql);

    return pIrp;
}

/**********************************************************************
 *
 *  HandleIrp_PerformCancel
 *
 *    This function removes the specified IRP from the list.
 *
 **********************************************************************/
NTSTATUS HandleIrp_PerformCancel(PIRPLISTHEAD pIrpListHead, PIRP pIrp)
{
    NTSTATUS NtStatus = STATUS_UNSUCCESSFUL;
    KIRQL kOldIrql;
    PIRPLIST pIrpListCurrent, pIrpListPrevious;

    KeAcquireSpinLock(&pIrpListHead->kspIrpListLock,
                                              &kOldIrql);

    pIrpListPrevious = NULL;
    pIrpListCurrent  = pIrpListHead->pListFront;

    while(pIrpListCurrent && NtStatus == STATUS_UNSUCCESSFUL)
    {
        if(pIrpListCurrent->pIrp == pIrp)
        {
            if(pIrpListPrevious)
            {
               pIrpListPrevious->pNextIrp = pIrpListCurrent->pNextIrp;
            }

            if(pIrpListHead->pListFront == pIrpListCurrent)
            {
               pIrpListHead->pListFront = pIrpListCurrent->pNextIrp;
            }
```

```
            if(pIrpListHead->pListBack == pIrpListCurrent)
            {
                pIrpListHead->pListBack = pIrpListPrevious;
            }

            KeReleaseSpinLock(&pIrpListHead->kspIrpListLock, kOldIrql);

            NtStatus = STATUS_SUCCESS;

            /*
             * We are going to allow the clean up function to complete the IRP.
             */
            pIrpListCurrent->pfnCleanUpIrp(pIrpListCurrent->pIrp,
                                          pIrpListCurrent->pContext);

            DbgPrint("HandleIrp_PerformCancel Complete Free Memory = 0x%0x \r\n",
                                                         pIrpListCurrent);

            KMem_FreeNonPagedMemory(pIrpListCurrent);

            pIrpListCurrent = NULL;

            KeAcquireSpinLock(&pIrpListHead->kspIrpListLock,
                                                  &kOldIrql);

        }
        else
        {
            pIrpListPrevious = pIrpListCurrent;
            pIrpListCurrent = pIrpListCurrent->pNextIrp;
        }
    }


    KeReleaseSpinLock(&pIrpListHead->kspIrpListLock, kOldIrql);

    return NtStatus;
}

/**********************************************************************
 *
 *  TdiExample_CancelRoutine
 *
 *    This function is called if the IRP is ever canceled
 *
 *    CancelIo() from user mode, IoCancelIrp() from the Kernel
 *
 **********************************************************************/
VOID TdiExample_CancelRoutine(PDEVICE_OBJECT DeviceObject, PIRP pIrp)
{
    PIRPLISTHEAD pIrpListHead = NULL;

    /*
     * We must release the cancel spin lock
     */

    IoReleaseCancelSpinLock(pIrp->CancelIrql);

    DbgPrint("TdiExample_CancelRoutine Called IRP = 0x%0x \r\n", pIrp);

    /*
     * We stored the IRPLISTHEAD context in our DriverContext on the IRP
     * before adding it to the queue so it should not be NULL here.
     */
```

```
    pIrpListHead = (PIRPLISTHEAD)pIrp->Tail.Overlay.DriverContext[0];
    pIrp->Tail.Overlay.DriverContext[0] = NULL;

    /*
     * We can then just throw the IRP to the PerformCancel
     * routine since it will find it in the queue, remove it and
     * then call our clean up routine.  Our clean up routine
     * will then complete the IRP.  If this does not occur then
     * our completion of the IRP will occur in another context
     * since it is not in the list.
     */
    HandleIrp_PerformCancel(pIrpListHead, pIrp);

}

/**********************************************************************
 *
 *  TdiExample_IrpCleanUp
 *
 *    This function is called to clean up the IRP if it is ever
 *    canceled after we have given it to the queueing routines.
 *
 **********************************************************************/
VOID TdiExample_IrpCleanUp(PIRP pIrp, PVOID pContext)
{
    pIrp->IoStatus.Status      = STATUS_CANCELLED;
    pIrp->IoStatus.Information = 0;
    pIrp->Tail.Overlay.DriverContext[0] = NULL;
    DbgPrint("TdiExample_IrpCleanUp Called IRP = 0x%0x \r\n", pIrp);

    IoCompleteRequest(pIrp, IO_NO_INCREMENT);
}
```

Alternatively you can use something like cancel safe IRP queues.

Process and Complete

This is where you simply process the request in line and complete it. If you don't return `STATUS_PENDING` then you are fine. This is what we have been doing with all the driver requests in most of the tutorials. We process them and then when we are done. We simply call `IoCompleteRequest` which is a mandatory call.

Creating IRPs

There was an extreme brief description of how to create and send IRPs in the previous article. We will go over those steps again here in more detail. We will also learn the difference between the APIs that we can use to create IRPs.

Step One: Create the IRP

There are a few APIs that can be used to create an IRP. As we already know, however there is a difference between them that we need to understand. The source in article 4 was very sloppy with IRP handling and this was simply to introduce IRPs without having to explain everything that we are explaining here.

There are Asynchronous IRPs and Synchronous IRPs. If you create an IRP using `IoAllocateIrp` or `IoBuildAsynchronousFsdRequest`, you have created an Asynchronous IRP. This means that you should set a completion routine and when the IRP is completed you need to call `IoFreeIrp`. You are in control of these IRPs and you must handle them appropriately.

If you create an IRP using `IoBuildDeviceIoControlRequest` or `IoBuildSynchronousFsdRequest`, then you have created a Synchronous IRP. Remember, `TdiBuildInternalDeviceControlIrp` is a macro and creates a synchronous IRP.

These IRPs are owned and managed **by the I/O Manager! Do not free them!** This is a common mistake I have seen with code on the internet that they call `IoFreeIrp` on failure! These IRPs MUST be completed using `IoCompleteRequest`. If you pass this IRP down to `IoCallDriver`, you do not need to complete it as the driver below will do it for you. If you do intercept the IRP with a completion routine, you will need to call `IoCompleteRequest` after you are done with it though.

Also remember before you consider creating an IRP make sure that you understand what IRQL your code will be called at. The benefit of using `IoAllocateIrp` is that it can be used at `DISPATCH_LEVEL` where as `IoBuildDeviceIoControlRequest` cannot.

Step Two: Setup the IRP Parameters

This is very simple and taking the TDI example the macro `TdiBuildSend` shows us how to do this. We use the `IoGetNextIrpStackLocation` and we simply set the parameters. We also set the Mdl and any other attributes we need to on the IRP itself.

Step Four: Send to the driver stack

This is very simple and we have done it over and over again. We simply use `IoCallDriver` to send the IRP down the stack.

Step Five: Wait and Clean up

If the driver returned any status besides "`STATUS_PENDING`" you are done. If you created the IRP asynchronously, then you either freed the IRP in the completion routine or set it for more processing here in which you do that now and free it with `IoAllocateIrp`.

If you created a synchronous IRP, you either let the I/O Manager handle it and you're done or you set the completion routine to return more processing in which case you do it here than call `IoCompleteRequest`.

If the status returned is "`STATUS_PENDING`" you now have a few choices. You can either wait here depending on the IRP or you can leave and complete it asynchronously. It all depends on your architecture. If you have created the IRP as asynchronous then your completion routine you set must check if the IRP was set to "Pending" and then set your event. That way you don't waste processing if there's no need. This is also why you don't wait on the event unless `STATUS_PENDING` was returned. Imagine how slow everything would be if all calls waited on the event no matter what!

If your IRP was created synchronously then the I/O Manager will set this event for you. You don't need to do anything unless you want to return the status more processing from the completion routine. Please read the section on "How Completion Works" to further understand what to do here.

Non-Paged Driver Code

If you remember in the first tutorial we learned about `#pragma` and the ability to put our driver code into different sections. There was the INIT section which was discardable and the PAGE section which put the memory into pagable code area. What about code that acquires a spinlock? What do we do when the code has to be non-pagable? We just don't specify `#pragma`! The default state of a loaded driver is to be in Non-Paged Memory we are actually forcing it into Paged memory with #pragma since we don't want the system to run out of physical memory when there's no need to be non-paged.

If you look at the code, you will notice that some of the `#pragma`'s are commented out. These are the functions that need to be non-paged as they use spinlocks and run at > `APC_LEVEL`. The reason I commented them out as opposed to just not putting them in is that I didn't want you to think I just forgot them and add them! I wanted to show that I made a decision to leave them out!

```
/* #pragma alloc_text(PAGE, HandleIrp_FreeIrpListWithCleanUp) */
/* #pragma alloc_text(PAGE, HandleIrp_AddIrp)                 */
/* #pragma alloc_text(PAGE, HandleIrp_RemoveNextIrp)          */
#pragma alloc_text(PAGE, HandleIrp_CreateIrpList)
#pragma alloc_text(PAGE, HandleIrp_FreeIrpList)
/* #pragma alloc_text(PAGE, HandleIrp_PerformCancel)          */
```

How Completion Works?

The completion works in a way that each device's STACK LOCATION may have an associated completion routine. This completion routine is actually called for the driver above it not for the current driver! The current driver knows when he completes it. So when the driver does complete it the completion routine of the current stack location is read and if it exists it's called. Before it is called the current `IO_STACK_LOCATION` is moved to point to the previous driver's location! This is important as we will see in a minute. If that driver does not complete it, it must propagate the pending status up by calling "`IoMarkIrpPending`" as we mentioned before. This is because if the driver returns `STATUS_PENDING`, it must mark the IRP as pending. If it doesn't return the same status as the lower level driver, it doesn't need to mark the IRP as pending. Perhaps it intercepted the `STATUS_PENDING` and waited for the completion. It could then stop the completion of the IRP and then complete it again while returning a status other than `STATUS_PENDING`.

That is probably a bit confusing so you refer back up to the talk on how to "Forward and Post Process". Now if your driver created the IRP you do not have to mark the IRP as pending! You know why? Because you don't have an `IO_STACK_LOCATION`! You are not on the device's stack! You will actually start to corrupt memory if you do this! You have two choices here. You have a few different choices here and none of them involve calling "`IoMarkIrpPending`"!!!

You will notice that example code may actually show a completion routine calling "`IoMarkIrpPending`" even though it created the IRP! This is not what should happen. In fact, if you look at real code, if a Synchronous IRP is created the completion routine usually doesn't exist or exists solely to return the status more processing.

I implemented a completion routine in our TDI Client driver. We create synchronous IRPs there however if you check out bit of debugging as follows:

```
kd> kb
ChildEBP RetAddr  Args to Child
fac8ba90 804e4433 00000000 80d0c9b8 00000000
    netdrv!TdiFuncs_CompleteIrp [.\tdifuncs.c @ 829]
fac8bac0 fbb20c54 80d1d678 80d0c9b8 00000000 nt!IopfCompleteRequest+0xa0
fac8bad8 fbb2bd9b 80d0c9b8 00000000 00000000 tcpip!TCPDataRequestComplete+0xa4
fac8bb00 fbb2bd38 80d0c9b8 80d0ca28 80d1d678 tcpip!TCPDisassociateAddress+0x4b
fac8bb14 804e0e0d 80d1d678 80d0c9b8 c000009a
    tcpip!TCPDispatchInternalDeviceControl+0x9b
fac8bb24 fc785d65 ffaaa3b0 80db4774 00000000 nt!IofCallDriver+0x3f
fac8bb50 fc785707 ff9cdc20 80db4774 fc786099
    netdrv!TdiFuncs_DisAssociateTransportAndConnection+0x94 [.\tdifuncs.c @ 772]
fac8bb5c fc786099 80db4774 ffaaa340 ff7d1d98
    netdrv!TdiFuncs_FreeHandles+0xd [.\tdifuncs.c @ 112]
fac8bb74 804e0e0d 80d33df0 ffaaa340 ffaaa350
    netdrv!TdiExample_CleanUp+0x6e [.\functions.c @ 459]
fac8bb84 80578ce9 00000000 80cda980 00000000 nt!IofCallDriver+0x3f
fac8bbbc 8057337c 00cda998 00000000 80cda980 nt!IopDeleteFile+0x138
fac8bbd8 804e4499 80cda998 00000000 000007dc nt!ObpRemoveObjectRoutine+0xde
fac8bbf4 8057681a ffb3e6d0 000007dc e1116fb8 nt!ObfDereferenceObject+0x4b
fac8bc0c 80591749 e176a118 80cda998 000007dc nt!ObpCloseHandleTableEntry+0x137
fac8bc24 80591558 e1116fb8 000007dc fac8bc60 nt!ObpCloseHandleProcedure+0x1b
fac8bc40 805916f5 e176a118 8059172e fac8bc60 nt!ExSweepHandleTable+0x26
fac8bc68 8057cfbe ffb3e601 ff7eada0 c000013a nt!ObKillProcess+0x64
fac8bcf0 80590e70 c000013a ffa25c98 804ee93d nt!PspExitThread+0x5d9
fac8bcfc 804ee93d ffa25c98 fac8bd48 fac8bd3c nt!PsExitSpecialApc+0x19
fac8bd4c 804e7af7 00000001 00000000 fac8bd64 nt!KiDeliverApc+0x1c3
kd> dds esp
fac8ba94  804e4433 nt!IopfCompleteRequest+0xa0
fac8ba98  00000000  ; This is the PDEVICE_OBJECT, it's NULL!!
fac8ba9c  80d0c9b8  ; This is IRP
fac8baa0  00000000  ; This is our context (NULL)
kd> !irp 80d0c9b8
Irp is active with 1 stacks 2 is current (= 0x80d0ca4c)
 No Mdl Thread ff7eada0:  Irp is completed.  Pending has been returned
     cmd  flg cl Device   File     Completion-Context
 [  f, 0]   0  0 80d1d678 00000000 fc786579-00000000
```

```
          \Driver\Tcpip    netdrv!TdiFuncs_CompleteIrp
           Args: 00000000 00000000 00000000 00000000

If there's only 1 stack how can it be on 2?
```

As you can see we are at `IO_STACK_LOCATION #2`, which does not exist. So the IRP actually starts out at a high `IO_STACK_LOCATION` which does not exist. If you remember, we need to call `IoGetNextIrpStackLocation` to set the parameters! This means that if we call `IoMarkIrpPending` here, we will essentially be accessing memory we shouldn't be as `IoMarkIrpPending` actually sets bits in the `IO_STACK_LOCATION`! The one thing that is also odd is that the device object is `NULL`. This is most likely because our stack location does not exist! We do not have an associated device object since we are not apart of this device stack. This is valid. By the way, the stack number may be incremented beyond the number of stacks for the I/O Manager and for the originator of the request. It's just not valid to attempt to actually use these stack locations!

Why STATUS_PENDING?

As if I haven't already confused you enough we need to talk about `STATUS_PENDING` and `IoMarkIrpPending`. What's the use? The use is because we can process IRP's asynchronously and the upper level drivers and I/O Manager need to know! The first part, `STATUS_PENDING` is returned as an optimization. So if we want to wait we ONLY do it for asynchronous operations. The second part is that the `IoMarkIrpPending` is actually what propagates the "`PendingReturned`" status on the IRP. That way we can optimize, so we don't always have to call `KeSetEvent` and only do it in the case where `STATUS_PENDING` was returned!

The other use is that a driver in the middle of the stack can change this status from `STATUS_PENDING` to `STATUS_SUCCESS` and not propagate the whole pending all the way up the driver stack. This way again the optimizations come into play and we don't have to do a lot of the extra handling that occurs on asynchronous operations. Remember that the IRP has two code paths, the return value up the stack and the completion path which may occur on a different threads. So you see why they need to be synchronized as well as propagate this status up both paths.

Overlapped I/O

The "`STATUS_PENDING`" architecture is essentially how Overlapped I/O is implemented. Just because the example source in this article uses `ReadFileEx` and `WriteFileEx` doesn't mean that `ReadFile` and `WriteFile` would not work here. They also work. If you look at the `CreateFile` API, I added a flag to enable Overlapped I/O. If you remove this flag the I/O Manager will actually block on `STATUS_PENDING` rather than return to the application. It will sit on an event until the I/O is completed. This is essentially why the user mode application was implemented using asynchronous I/O. Give these different methods a try!

Other Resources

The following are other resources and articles on IRP Handling that you may want to refer to and read.

- IRP Cheat Sheet Part 1
- IRP Cheat Sheet Part 2

These are "cheat sheets" which simply show sample code on how to handle IRPs. I am skeptical on the information in Cheat Sheet 2 on the IRP Completion routines which mark the Synchronous IRPs as Pending! Remember what I talked about the IRP completion routine is called with the stack location of that device. If you allocated that IRP, it doesn't mean you are on the device stack! I have not tried the code myself, so I could be missing something in the implementation.

- Completing IRPs
- Implementing an I/O Completion Routine
- Handling IRPs
- The Windows Driver Model Simplifies Management of Device Driver I/O Requests

There are many other resources out on the web and the URLs I provided will probably be gone or moved someday!

Example Source

The example source will build six binaries as listed here.

```
CHATCLIENT.EXE    - Winsock Chat Client
CHATCLIENTNET.EXE - Lightbulb Chat Client
CHATSERVER.EXE    - Winsock Chat Server
DRVLOAD.EXE       - Example TDI Client Driver Loader
NETDRV.SYS        - Example TDI Client Driver
NETLIB.LIB        - Lightbulb Library
```

The TDI Client Driver that was created can be used using a simple API set as implemented in *NETLIB.LIB*. I named it the "`LightBulb`" API set as a play on "Sockets". There is essentially two clients where one uses Winsock and one uses `Lightbulbs` simply for example purposes.

Driver Architecture

The architecture of the driver is very simple. It simply queues all read and write IRPs. It has a special write thread that it created in the system process. This is just to demonstrate queuing IRPs and performing Asynchronous operations. The call to write network data can return to user mode without having to wait for the data to be sent or having to copy the data. The read is the same the IRPs are queued and when the data receive callback occurs those are completed. The source is fully commented.

Building the Source

First as always make sure that all makefiles point to the location of your DDK. The current makefiles assume the root of the same drive the source is on at *\NTDDK\INC*. The second is to make sure that your Visual Studio environment variables are setup using *VCVARS32.BAT*.

I created a new make file at the root of the "network" directory which you can then use to build all directories. The first command you can use is "nmake dir". This command will fail if any of the directory already exists. What it will do is pre-create all directories needed to build the source. Sometimes the source build will fail if the directories do not already exist.

```
C:\Programming\development\DEBUG\private\src\drivers\network>nmake dir

Microsoft (R) Program Maintenance Utility   Version 6.00.8168.0
Copyright (C) Microsoft Corp 1988-1998. All rights reserved.

        mkdir ..\..\..\..\bin
```

The second thing that you can do is "nmake" or "nmake all" to build the sources. It will go into each directory and build all 6 binaries in the correct order.

```
C:\Programming\development\DEBUG\private\src\drivers\network>nmake

Microsoft (R) Program Maintenance Utility   Version 6.00.8168.0
Copyright (C) Microsoft Corp 1988-1998. All rights reserved.

        cd chatclient
        nmake

Microsoft (R) Program Maintenance Utility   Version 6.00.8168.0
Copyright (C) Microsoft Corp 1988-1998. All rights reserved.

        cl /nologo /MD /W3 /Oxs /Gz /Zi  /I "..\..\..\..\inc"  /D "WIN32" /D "_W
INDOWS"  /Fr.\obj\i386\\ /Fo.\obj\i386\\ /Fd.\obj\i386\\ /c .\client.c
client.c
        link.exe /LIBPATH:..\..\..\..\lib  /DEBUG /PDB:..\..\..\..\..\bin\SYMBOL
```

```
S\chatclient.PDB  /SUBSYSTEM:CONSOLE /nologo kernel32.lib  Advapi32.lib  WS2_32.
LIB /out:..\..\..\..\..\bin\chatclient.exe .\obj\i386\client.obj kernel32.lib  A
dvapi32.lib  WS2_32.LIB
        rebase.exe -b 0x00400000 -x ..\..\..\..\..\bin\SYMBOLS -a ..\..\..\..\..
\bin\chatclient
REBASE: chatclient       - unable to split symbols (2)
```

The last option you have is "nmake clean" which will then go into each directory and delete the object files. This will then cause that project to be rebuilt upon typing "nmake" or "nmake all". Of course you can type "nmake and "nmake clean" in any of the application directories as well however this is a convenient way to build all binaries at one time.

```
C:\Programming\development\DEBUG\private\src\drivers\network>nmake clean

Microsoft (R) Program Maintenance Utility   Version 6.00.8168.0
Copyright (C) Microsoft Corp 1988-1998. All rights reserved.

        cd chatclient
        nmake clean

Microsoft (R) Program Maintenance Utility   Version 6.00.8168.0
Copyright (C) Microsoft Corp 1988-1998. All rights reserved.

Deleted file - C:\Programming\development\DEBUG\private\src\drivers\network\chat
client\obj\i386\client.obj
Deleted file - C:\Programming\development\DEBUG\private\src\drivers\network\chat
client\obj\i386\client.sbr
Deleted file - C:\Programming\development\DEBUG\private\src\drivers\network\chat
client\obj\i386\vc60.pdb
```

Chat Server

The chat server is a very simple implementation. It simply accepts connections and puts these connections into a list. Any time it receives data from any client it simply broadcasts this to all other clients.

Chat Clients

There are two chat clients but they both are essentially implemented the same. The only difference is that one talks to the Winsock API and the other uses our "`Lighbulb`" API. These clients simply print any incoming data and send any data that the user typed in. They are console applications so any time the user types in input, the incoming output is blocked until you are finished typing.

Chat Protocol

The chat protocol is extremely simple. The first packet sent will be the name of the client and used to identify him to all other clients. The rest are simply broadcast as strings. There is no packet header. So the server and clients all assume that each bit of chat text sent will be read in one receive! This is extremely prone for error and was just used as an example. To beef it up you may want to consider actually creating a protocol!

Bugs!

There are essentially three bugs that are known in the source code. Two of them are actually things just left out of the implementation and the other is just something I saw that I didn't feel like fixing. This is example code you are lucky it compiles! Have you ever seen books where they give code that you know would not compile! Well, here at least this is working in the most simplest of cases. The bugs are there for you to fix. I figure that I'll give some guidance and you can get better acquainted with the code by fixing these bugs. I did run some of the driver verifier tests on the source to make sure there were no bluntly obvious bugs but there has not been extensive testing. Then again this isn't a commercial software. There could be other bugs, if you find any see if you can fix them. If you need some help let me know.

Bug One: TDI Client Detect Disconnect

There is no implementation to detect when the client disconnects from the server. If the server is aborted while the client is connected it simply does not know and continues to attempt to send data. The return value from `TDI_SEND` is ignored and there are no other registered events to get notified of a disconnect. The implementation is simply not there. This is now your job. You must implement a method to detect when the connection has disconnected. There are a variety of implementations that could do this.

Bug Two: No Protocol

There is no protocol implemented between the clients and server. A protocol should be implemented that does not rely on receiving the entire packet ever read and be more flexible! Perhaps add even a simple file transfer!

Bug Three: Incorrect Display

There is a bug that involves two connected clients. This bug actually will occur using either client implementats, TDI or Sockets. The bug occurs when one client is about to type a message but it doesn't send it. The other client then sends 5 or so messages. The client that didn't send any message then sends his message. This message is corrupted, the name is overwritten with the data being sent. As a hint, you may want to investigate the data being sent and pay attention to the "\r\n" pairings.

Conclusion

This article implemented a simple chat program that used sockets and an implementation of a TDI Client. There was also a lot of information on how to handle IRPs along with links to other locations to further your education. IRPs are the backbone of driver development and they are key to understand how to write device drivers for Windows. Please remember that there are a lot of misinformation, missing information and bad examples out there so make sure that you visit a few different sites and attempt a few techniques so that you can distinguish what is correct and what is incorrect.

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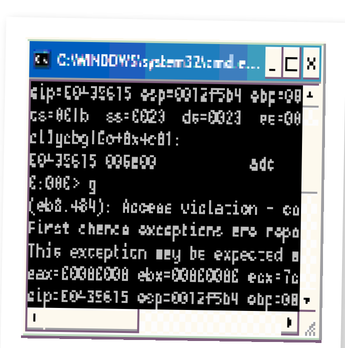
About the Author



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Toby Opferman has worked in just about all aspects of Windows development including applications, services and drivers.

He has also played a variety of roles professionally on a wide range of projects. This has included pure researching roles, architect roles and developer roles. He also was also solely responsible for debugging traps and blue screens for a number of years.

Previously of Citrix Systems he is very experienced in the area of Terminal Services. He currently works on Operating Systems and low level architecture at Intel.

He has started a youtube channel called "Checksum Error" that focuses on software.
https://www.youtube.com/channel/UCMN9q8DbU0dnllWpVRvn7Cw

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