C++

C++, a class is a user-defined type or data structure that contains variables and functions as its members. It provides a way to encapsulate data and functions together in a single unit, which can be used to represent real-world entities.

Classes are defined using the class keyword, followed by the name of the class. The class definition is then enclosed within curly braces, and the member variables and functions are defined within the class definition. Here is an example of a simple class in C++:

```
class Employee

{

  public:

    std::string name;

    int age;

    double salary;



    void printInfo()

    {

      std::cout << "Name: " << name << std::endl;

      std::cout << "Age: " << age << std::endl;

      std::cout << "Salary: " << salary << std::endl;

    }

};
```

In the example above, the Employee class has three member variables: name, age, and salary. It also has a member function called printInfo, which prints the values of the member variables to the console.

To use a class in a C++ program, we first need to create an object of the class. An object is an instance of a class and is created using the class name followed by the object name, like this:

```
Employee emp1;
```

Once we have an object of the class, we can access the member variables and functions of the class using the dot operator (.). For example, we can set the values of the member variables like this:

```
emp1.name = "John Smith";

emp1.age = 35;

emp1.salary = 50000.00;
```

And we can call the member function like this:

```
emp1.printInfo();
```

Classes in C++ also support inheritance, which allows one class to inherit the member variables and functions of another class. This allows us to create a base class with common functionality and then create derived classes that inherit this functionality and add their own unique features.

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INHERTANCE

Inheritance is a concept in object-oriented programming where a class can inherit properties and behavior from a parent class. In the context of the example of shapes, we can have a base class called "Shape" that has a method called "area()" to calculate the area of the shape. We can then create derived classes for specific shapes such as "Rectangle" and "Circle" which will inherit the "area()" method from the "Shape" class.

The "Rectangle" class can have its own properties such as width and height and can override the "area()" method to implement the formula for calculating the area of a rectangle (width * height). The "Circle" class can have its own property called "radius" and can also override the "area()" method to implement the formula for calculating the area of a circle (pi * radius * radius).

In this way, the derived classes can inherit common behavior and properties from the base class and also have their own unique properties and behavior. This allows us to reuse code and avoid duplicating it in each derived class.

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VIRTUAL FUNCTUON

In C++, a virtual method is a member function that is declared within a base class and is re-defined (overriden) by a derived class. When a derived class inherits from a base class, it can define its own implementation of the virtual method, which will be used instead of the base class implementation when the method is called on an object of the derived class.

The use of virtual methods allows for the creation of a common interface for related classes, while still allowing the derived classes to have their own specific behavior. This is known as polymorphism.

For example, consider a base class Shape that has a virtual method area() which calculates the area of the shape. A derived class Circle might override the area() method to use the formula for the area of a circle (pi*r^2), while a derived class Rectangle might override the area() method to use the formula for the area of a rectangle (*lw).

To declare a virtual method in a base class, the virtual keyword is used in the method declaration. For example:

```
class Shape

{

public:

  virtual double area() = 0;

  // other members of the class

};
```

To override a virtual method in a derived class, the derived class must provide its own implementation of the method, using the same name and parameter list as the base class method. For example:

```
class Circle : public Shape

{

public:

  double area() override;

  // other members of the class

};


double Circle::area()

{

  // implementation of the area() method for a Circle object

}
```

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OMNET++

1. **CustomTcpEchoApp** is a class that represents a TCP echo server application. It extends the CustomTcpServerHostApp class and overrides certain methods to implement the desired behavior of the echo server.
2. **CustomTcpEchoAppThread** is a class that represents a thread of execution in the echo server. It extends the TcpServerThreadBase class and overrides certain methods to implement the desired behavior of the thread.
3. **CustomTcpServerHostApp** is a class that represents a TCP server application. It extends the ApplicationBase class and implements the TcpSocket::ICallback interface. It manages a collection of TcpServerThreadBase objects, one for each connected client.
4. **TcpServerThreadBase** is a class that represents a thread of execution in a TCP server. It extends the cSimpleModule class and implements the TcpSocket::ICallback interface. It represents a connection with a client and handles the communication with that client.
5. **TcpSocket** is a class that represents a TCP socket. It provides a number of methods for sending and receiving data, connecting and disconnecting, and managing the state of the socket.
6. **ICallback** is an interface that defines a set of callback methods that can be implemented by a class to receive notifications about the state and events of a TcpSocket. Classes that implement this interface can register themselves with a TcpSocket to receive these notifications.
7. **Packet** is a class that represents a data packet in the simulation. It provides methods for accessing and modifying the header and payload of the packet, as well as methods for adding and removing packet header tags.
8. **Protocol** is a class that represents a network protocol. It provides a number
9. **DispatchProtocolReq** is a class that represents a packet header tag that specifies the protocol to be used for sending the packet. It is used by the sendDown method of CustomTcpEchoApp to specify that the packet should be sent using the TCP protocol.
10. **CreationTimeTag** is a class that represents a packet header tag that stores the time at which the packet was created. It is used by the dataArrived method of CustomTcpEchoAppThread to calculate the delay of the received packet.
11. **LifecycleOperation** is a class that represents an operation that can be performed on a module during its lifecycle (e.g., start, stop, crash). The handleStartOperation, handleStopOperation, and handleCrashOperation methods of CustomTcpServerHostApp are called when the server module receives a start, stop, or crash operation, respectively.
12. **NodeStatus** is a class that represents the current status of a simulation node (e.g., up, down, starting up, shutting down). The handleStartOperation and handleStopOperation methods of CustomTcpServerHostApp use this class to check the status of the node before starting or stopping the server.
13. **L3AddressResolver** is a class that provides methods for resolving network addresses. The handleMessageWhenUp method of CustomTcpServerHostApp uses this class to resolve the address of the server.

14. **SctpPeer** is a class that represents a peer in an SCTP connection. It is not directly related to the provided implementation, but it is mentioned in the code as a forward declaration.
15. **SctpCommand** is a class that represents a command for an SCTP socket. It is not directly related to the provided implementation

the code for a custom TCP echo application and server host in the INET Framework for the OMNeT++ network simulator.

The **CustomTcpEchoApp** class is derived from the **CustomTcpServerHostApp** class, which itself is derived from the ApplicationBase class in the INET Framework. **CustomTcpEchoApp** overrides the initialize, finish, and refreshDisplay methods of the **CustomTcpServerHostApp** class. It also has a sendDown method which is used to send packets down the protocol stack and a delay variable which represents the delay of the echo application.

The **CustomTcpEchoApp** class has several member variables such as *echoFactor*, *bytesRcvd*, *bytesSent*, *packetsSent, packetsRcvd, avrgDelay, avrgDelayCounter, firstSentPacketTime, lastSentPacketTime, m_PreviousPacketDelay, and m_jitterAccumulator*. **The purpose of these variables is not clear from their names.**

The **CustomTcpEchoApp** class has a nested class called **CustomTcpEchoAppThread**, which is derived from the **TcpServerThreadBase** class. **CustomTcpEchoAppThread** overrides the established, dataArrived, handleMessage, timerExpired, and init methods of the TcpServerThreadBase class. It also has a member variable echoAppModule which is a pointer to a CustomTcpEchoApp object.

The **CustomTcpServerHostApp** class is responsible for creating and managing TCP server threads that handle incoming connections. It has a **TcpSocket** member called serverSocket which is used to listen for incoming connections and a **SocketMap** member called socketMap which stores the active sockets.

The **CustomTcpServerHostApp** class also has a ThreadSet member called **threadSet** which stores the set of server threads.

CustomTcpServerHostApp overrides several methods of the **ApplicationBase**, **TcpSocket::ICallback**, and cSimpleModule classes. These include initialize, numInitStages, handleMessageWhenUp, finish, refreshDisplay, socketAvailable, socketClosed, handleStartOperation, handleStopOperation, and handleCrashOperation.

The **TcpServerThreadBase** class is the base class for server threads in the INET Framework. It is derived from the cSimpleModule class and has a CustomTcpServerHostApp member called hostmod. It also has virtual methods such as established, dataArrived, handleMessage, timerExpired, and init.

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In the **CustomTcpEchoApp** class, the initialize method is used to initialize the delay and echoFactor member variables. It also sets the bytesRcvd and bytesSent variables to 0 and starts watching these variables.

The **sendDown** method is used to send a packet down the protocol stack. It adds a DispatchProtocolReq tag to the packet and sets the protocol to TCP. It then sends the packet on the socketOut gate.

The **refreshDisplay** method updates the display string for the module with the number of threads and the number of bytes received and sent.

The **finish** method is called at the end of the simulation and is used to print some statistics such as the number of bytes and packets received and sent, the throughput, and the average delay.

In the **CustomTcpEchoAppThread** class, the established method is called when a connection with a client is established. It sends the first packet to the client with a delay of echoDelay.

The dataArrived method is called when data is received from the client. It sends the received data back to the client with a delay of echoDelay.

The **handleMessage** method handles self-messages and messages from the client. If the message is a self-message, it sends the next packet to the client with a delay of echoDelay. If the message is from the client, it sends the received data back to the client with a delay of echoDelay.

The **timerExpired** method is called when a timer expires. It sends the next packet to the client with a delay of echoDelay.

The **init** method is called to initialize the server thread with a pointer to the CustomTcpEchoApp module and a TcpSocket object. It sets the echoAppModule member variable to the pointer to the CustomTcpEchoApp module.

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1. The **CustomTcpEchoApp** and **CustomTcpEchoAppThread** classes are part of a custom TCP echo application and server host in the INET Framework for the OMNeT++ network simulator.
2. The **CustomTcpEchoApp** class is derived from the **CustomTcpServerHostApp** class and overrides several of its methods, including initialize, finish, and refreshDisplay.
3. The **CustomTcpEchoApp** class has a delay member variable which represents the delay of the echo application, and an echoFactor member variable which has an unknown purpose.
4. The **CustomTcpEchoApp** class has several member variables for tracking statistics such as the number of bytes and packets received and sent, and the average delay.

5. The **CustomTcpEchoApp** class has a nested class called **CustomTcpEchoAppThread** which is derived from the **TcpServerThreadBase** class and overrides several of its methods.
6. The **CustomTcpEchoAppThread** class has an echoAppModule member variable which is a pointer to a CustomTcpEchoApp object.
7. The **CustomTcpServerHostApp** class is responsible for creating and managing TCP server threads that handle incoming connections. It has a TcpSocket member called serverSocket and a SocketMap member called socketMap for storing active sockets.
8. The **CustomTcpServerHostApp** class has a ThreadSet member called threadSet which stores the set of server threads.
9. The **CustomTcpServerHostApp** class overrides several methods of the ApplicationBase, TcpSocket::ICallback, and cSimpleModule classes to handle events such as incoming connections, data arrival, and socket closure.
10. The **TcpServerThreadBase** class is the base class for server threads in the INET Framework. It has a CustomTcpServerHostApp member called hostmod and several virtual methods.
11. The **CustomTcpEchoApp** class has a sendDown method which is used to send packets down the protocol stack. It adds a DispatchProtocolReq tag to the packet and sets the protocol to TCP before sending it on the socketOut gate.
12. The **CustomTcpEchoApp** class has a finish method which is called at the end of the simulation to print statistics such as the number of bytes and packets received and sent, the throughput, and the average delay.
13. In the **CustomTcpEchoAppThread** class, the established method is called when a connection with a client is established. It sends the first packet to the client with a delay of echoDelay.
14. The **dataArrived** method is called when data is received from the client. It sends the received data back to the client with a delay of echoDelay.
15. The **handleMessage** method handles self-messages and messages from the client. If the message is a self-message, it sends the next packet to the client with a delay of echoDelay. If the message is from the client, it sends the received data back to the client with a delay of echoDelay.
16. The **timerExpired** method is called when a timer expires. It sends the next packet to the client with a delay of echoDelay.
17. The `

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CustomTcpEchoAppThread class has an init method which is called to initialize the server thread with a pointer to theCustomTcpEchoAppmodule and aTcpSocketobject. It sets theechoAppModulemember variable to the pointer to theCustomTcpEchoAppmodule.

18. The **CustomTcpServerHostApp** class has aremoveThread` method which is called to remove a server thread from the set of active threads.

19. The **CustomTcpServerHostApp** class has a threadClosed method which is called when a server thread is closed. It removes the thread from the set of active threads and deletes the associated socket.

20. The **CustomTcpServerHostApp** class has a handleStartOperation method which is called when the module is starting. It binds the serverSocket to a local address and listens for incoming connections.
21. The **CustomTcpServerHostApp** class has a handleStopOperation method which is called when the module is stopping. It closes the serverSocket and deletes all active sockets.
22. The **CustomTcpServerHostApp** class has a handleCrashOperation method which is called when the module crashes. It closes the serverSocket and deletes all active sockets.
23. The **CustomTcpServerHostApp** class has a socketAvailable method which is called when a new connection is available on the serverSocket. It creates a new server thread and adds it to the set of active threads.
24. The **CustomTcpServerHostApp** class has a socketClosed method which is called when a socket is closed. It removes the associated server thread from the set of active threads and deletes the socket.
25. The **CustomTcpServerHostApp** class has a refreshDisplay method which updates the display string for the module with the number of active threads.
26. The **TcpServerThreadBase** class has a handleMessage method which handles messages from the client and self-messages. If the message is a self-message, it calls the timerExpired method. If the message is from the client, it calls the dataArrived method.
27. The **TcpServerThreadBase** class has a dataArrived method which is called when data is received from the client. It has an empty implementation and is intended to be overridden by derived classes.
28. The **TcpServerThreadBase** class has a timerExpired method which is called when a timer expires. It has an empty implementation and is intended to be overridden by derived classes.
29. The **TcpServerThreadBase** class has a socketDataArrived method which is called when data is received on the socket. It has an empty implementation and is intended to be overridden by derived classes.
30. The **TcpServerThreadBase** class has a socketPeerClosed method which is called when the peer closes the socket. It has an empty implementation and is intended to be overridden by derived classes.

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- The **CustomTcpEchoApp** and **CustomTcpEchoAppThread** classes are implementations of a TCP echo application.
- The **CustomTcpEchoApp** class is a subclass of **CustomTcpServerHostApp** and the **CustomTcpEchoAppThread** class is a subclass of **TcpServerThreadBase**.
- The **CustomTcpEchoApp** class has several member variables, including delay, echoFactor, bytesRcvd, bytesSent, packetsSent, packetsRcvd, avrgDelay, avrgDelayCounter, firstSentPacketTime, lastSentPacketTime, m_PreviousPacketDelay, and m_jitterAccumulator.
- The **delay** variable stores the value of the echoDelay parameter, which specifies the delay between the sending of each packet.
- The **echoFactor** variable stores the value of the echoFactor parameter, which is not used in the provided code.

- The bytesRcvd, bytesSent, packetsSent, and packetsRcvd variables store the number of bytes and packets received and sent by the server.
- The avrgDelay, avrgDelayCounter, firstSentPacketTime, lastSentPacketTime, m_PreviousPacketDelay, and m_jitterAccumulator variables are used to calculate various statistics about the packets, such as the average delay, the first and last sent packet times, the previous packet delay, and the jitter.
- The initialize method of the CustomTcpEchoApp class initializes the delay and echoFactor variables and sets up watches on the bytesRcvd, bytesSent, `packetsSent

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packet header tags are used to calculate the delay of packets by adding a CreationTimeTag to each packet when it is sent and then retrieving the value of the tag when the packet is received.

<u>Here's how it works in more detail:</u>

1. When a packet is sent, a CreationTimeTag is added to the packet's header using the addTagIfAbsent method and the current simulation time is set as the tag's creation time.
2. When a packet is received, the dataArrived method is called and the packet is passed as an argument.
3. The packet's data is accessed using the peekData method and the CreationTimeTags are retrieved using the getAllTags method.
4. The creation time of each CreationTimeTag is retrieved using the getCreationTime method.
5. The delay of the packet is calculated by subtracting the creation time from the current simulation time.
6. The delay is then used to update various statistics, such as the average delay, the previous packet delay, and the jitter.

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Here is a list of the methods that would be called in the correct order when a packet is sent by the client and received by the server, and then echoed by the server and received by the client, along with an explanation of the conditions under which each method is called:

1. sendDown method of CustomTcpEchoApp on the server side: This method is called when the server wants to send a packet down to the transport layer.
2. dataArrived method of CustomTcpEchoAppThread on the server side: This method is called when data arrives at the server from the transport layer.
3. sendDown method of CustomTcpEchoApp on the server side: This method is called when the server wants to send a packet down to the transport layer as a response to the packet received from the client.
4. socketDataArrived method of CustomTcpServerHostApp on the server side: This method is called when data arrives at the server's socket from the transport layer.

5. dataArrived method of CustomTcpEchoAppThread on the client side: This method is called when data arrives at the client from the transport layer.
6. sendDown method of CustomTcpEchoApp on the client side: This method is called when the client wants to send a packet down to the transport layer.
7. dataArrived method of CustomTcpEchoAppThread on the client side: This method is called when data arrives at the client from the transport layer.
8. sendDown method of CustomTcpEchoApp on the client side: This method is called when the client wants to send a packet down to the transport layer as a response to the packet received from the server.
9. socketDataArrived method of CustomTcpServerHostApp on the client side: This method is called when data arrives at the client's socket from the transport layer.
10. finish method of CustomTcpEchoApp on the server and client sides: This method is called when the simulation finishes and the server and client want to print out statistics about the communication between them.

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Here is a list of method executions in the order they are called when a packet is sent by the client, received by the server, echoed by the server, and received by the client:

1. sendDown method of CustomTcpEchoApp on the client side: This method is called when the client wants to send a packet down to the transport layer.
2. socketDataArrived method of CustomTcpServerHostApp on the server side: This method is called when data arrives at the server's socket from the transport layer.
3. dataArrived method of CustomTcpEchoAppThread on the server side: This method is called when data arrives at the server from the transport layer.
4. sendDown method of CustomTcpEchoApp on the server side: This method is called when the server wants to send a packet down to the transport layer as a response to the packet received from the client.
5. socketDataArrived method of CustomTcpServerHostApp on the client side: This method is called when data arrives at the client's socket from the transport layer.
6. sendDown method of CustomTcpEchoApp on the client side: This method is called when the client wants to send a packet down to the transport layer.
7. dataArrived method of CustomTcpEchoAppThread on the client side: This method is called when data arrives at the client from the transport layer.
8. sendDown method of `CustomT

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- CustomTcpEchoApp::sendDown: This method is called when the server is ready to send the echoed packet back to the client. It is called with the packet to be sent as the argument.
- CustomTcpEchoApp::initialize: This method is called during the initialization stage of the server application. It sets up various variables and registers them for watch.
- CustomTcpEchoAppThread::established: This method is called when a connection is established between the server and the client.

- CustomTcpEchoAppThread::dataArrived: This method is called when a packet is received by the server from the client. It is called with the received packet and a bool indicating whether the packet is marked as urgent or not.
- CustomTcpEchoAppThread::handleMessage: This method is called when a message is received by the server application. It determines the type of message and takes appropriate action.
- CustomTcpEchoAppThread::timerExpired: This method is called when a timer set by the server application expires.
- CustomTcpEchoApp::finish: This method is called when the simulation finishes. It prints out various statistics about the packets sent and received by the server.
- CustomTcpEchoApp::refreshDisplay: This method is called to update the display string of the server application. It shows the number of threads and the number of bytes sent and received.

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There is two main classes: CustomTcpEchoApp and CustomTcpEchoAppThread. CustomTcpEchoApp is a subclass of CustomTcpServerHostApp, which is a subclass of ApplicationBase. This means that CustomTcpEchoApp has all the functionality of a basic application in INET, as well as the specific functionality of a TCP server. CustomTcpEchoAppThread is a subclass of TcpServerThreadBase, which is a simple module that handles the communication between a server and a single client.

When the CustomTcpEchoApp is initialized, it sets the value of the "echoDelay" and "echoFactor" parameters and initializes counters for bytes received and sent, and packets received and sent. The sendDown method is used to send a packet down the stack towards the TCP layer, adding a DispatchProtocolReq tag to the packet to specify that it should be sent via TCP. The method also updates the bytesSent and packetsSent counters and emits a packetSentSignal signal.

The refreshDisplay method updates the display string of the CustomTcpEchoApp object to show the number of threads (connections with clients), and the number of bytes and packets received and sent. The finish method is called when the simulation is ending, and it displays some statistics about the server's performance, including the throughput, the time of the first and last sent packets, the average delay, and the average jitter.

CustomTcpEchoAppThread handles the communication with a single client. When a connection with a client is established, the established method is called. The dataArrived method is called when a packet is received from the client, and it updates the bytesReceived and packetsReceived counters and emits a packetReceivedSignal signal. The handleMessage method is called when a self-message (timer) or another kind of message is received, and it delegates the handling to the timerExpired method if the message is a timer. The init method is used to initialize the thread with a pointer to the CustomTcpEchoApp object and a TcpSocket for the connection with the client. The threadClosed method is called when the thread is closed.

Finally, the CustomTcpServerHostApp class is responsible for creating and managing the threads (CustomTcpEchoAppThread objects) that handle the communication with the clients. It maintains a SocketMap object to keep track of the sockets and a ThreadSet object to keep track of the threads. The handleMessageWhenUp method is called when a message is received and the application is in the

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CustomTcpEchoApp and CustomTcpEchoAppThread. CustomTcpEchoApp is a subclass of CustomTcpServerHostApp, which is a class that provides functionality for a TCP server application. It has a number of methods that are called at different stages of the server's execution.

The initialize method is called when the server is first set up. It sets some member variables, such as the delay and echo factor, based on parameters provided in the simulation configuration. It also sets up some "watches" on other member variables, which allows them to be monitored during the simulation.

The sendDown method is called when the server wants to send a packet down the stack, towards the transport layer. It takes a packet as an argument and updates some counters to keep track of the number of bytes and packets sent. It then adds a special "tag" to the packet to specify that it should be sent using the TCP protocol. Finally, it sends

the packet down the stack using the "socketOut" gate.

The refreshDisplay method is called periodically during the simulation to update the visual representation of the server in the simulation environment. It sets the text that is displayed next to the server's icon to show the number of threads (connections) the server has, and the number of bytes and packets received and sent.

The finish method is called when the simulation is ending. It prints out some statistics about the server's performance, such as the number of bytes and packets received and sent, the throughput (amount of data transmitted per second), and the delay (amount of time it takes for a packet to be sent and received). It also calculates and prints the average jitter (variation in delay) for the packets received by the server.

The CustomTcpEchoAppThread class represents a separate thread (or connection) for each client that connects to the server. It has several methods that are called at different points during the execution of the thread.

The established method is called when a connection with a client is established.

The dataArrived method is called when a packet is received from a client. It updates some counters to keep track of the number of bytes and packets received and emits a signal to indicate that a packet was received. It also extracts a special "tag" from the packet that indicates the time at which the packet was created, and uses this to calculate the delay for the packet. It also calculates the jitter for the received packets by comparing the current delay with the previous delay. Finally, it echoes the received packet back to the client by calling the sendDown method of the CustomTcpEchoApp class.

The connectionClosed method is called when the connection with a client is closed. It updates some counters to keep track of the number of bytes and packets received and sent and prints out some statistics about the thread's performance.

The peerClosed method is called when the connection with a client is closed from the client's side. It updates some counters to keep track of the number of bytes and packets received and sends a message to close the connection from the server's side as well.

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A TCP echo application in C++, which is essentially a program that sends back any data that it receives. There are two main classes in this code: CustomTcpEchoApp and CustomTcpEchoAppThread. CustomTcpEchoApp is a subclass of CustomTcpServerHostApp, which is a class that handles the creation and management of socket connections for the application. CustomTcpEchoApp has several member variables such as delay, echoFactor, bytesRcvd, bytesSent, packetsSent, and packetsRcvd, which are used to store information about the packets that are sent and received by the application. The class also has several member functions, including sendDown(), initialize(), finish(), and refreshDisplay(). These functions are called at different stages of the application's execution to perform specific tasks.

CustomTcpEchoAppThread is a subclass of TcpServerThreadBase, which is a class that handles the communication between the application and individual clients that are connected to it. CustomTcpEchoAppThread has a member variable called echoAppModule, which is a pointer to an instance of the CustomTcpEchoApp class. The class also has several member functions, including established(), dataArrived(), handleMessage(), timerExpired(), and init(). These functions are called at different stages of the communication with a client to perform specific tasks.

When a client sends a packet to the server, the packet is received by the server and passed to the dataArrived() function of the CustomTcpEchoAppThread class. This function processes the packet and then calls the sendDown() function of the CustomTcpEchoApp class to send the packet back to the client. The sendDown() function adds a TCP protocol tag to the packet and then sends it to the client through the "socketOut" gate. When the packet is received by the client, it is passed to the handleMessage() function of the CustomTcpEchoAppThread class, which processes the packet and updates the appropriate member variables of the CustomTcpEchoApp class.

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This is a C++ implementation of a TCP echo application. This application is a server that listens for incoming client connections and echoes any data received back to the client.

There are two main classes in the code: CustomTcpEchoApp and CustomTcpEchoAppThread. CustomTcpEchoApp is derived from the CustomTcpServerHostApp class, which is itself derived from the ApplicationBase class. This class is responsible for setting up the server socket, handling incoming client connections, and creating a new thread for each connected client.

CustomTcpEchoAppThread is a class that is responsible for handling the communication with a single client. It is derived from the TcpServerThreadBase class, which provides the basic functionality for a server thread. CustomTcpEchoAppThread overrides several virtual methods to implement the echo functionality.

When a client sends data to the server, it is received by the CustomTcpEchoAppThread::dataArrived method. This method processes the received data and sends it back to the client by calling the CustomTcpEchoApp::sendDown method. This method adds the necessary TCP and dispatch protocol headers to the packet and sends it out through the socket connection.

The CustomTcpEchoApp class also includes several variables and methods for collecting statistics on the server's performance. These include the number of bytes and packets received and sent, the average delay between when a packet is received and when it is echoed back to the client, and the throughput of the server (measured in kbps). These statistics are displayed at the end of the simulation in the CustomTcpEchoApp::finish method.

In addition to echoing data back to the client, the CustomTcpEchoAppThread class also calculates the jitter (variation in delay) for the packets received from the client. It does this by comparing the delay of each packet to the delay of the previous packet and adding the difference to an accumulator. The average jitter is then calculated by dividing the accumulator by the number of packets received.

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CustomTcpEchoApp is a subclass of CustomTcpServerHostApp, which is a class that extends ApplicationBase and implements the TcpSocket::ICallback interface. This class is responsible for handling incoming connections and managing a socket map to keep track of the open sockets. It has a method threadClosed that removes a TcpServerThreadBase instance from the thread set when it is closed. It also has methods to handle start, stop, and crash operations, as well as methods to handle messages when the application is up and to refresh the display.

CustomTcpEchoApp has several member variables, including delay, echoFactor, bytesRcvd, bytesSent, packetsSent, packetsRcvd, avrgDelay, avrgDelayCounter, firstSentPacketTime, lastSentPacketTime, m_PreviousPacketDelay, and m_jitterAccumulator. It also has a method sendDown to send a message down the protocol stack, and methods initialize, finish, and refreshDisplay to perform initialization, finalization, and display tasks, respectively.

CustomTcpEchoAppThread is a subclass of TcpServerThreadBase, which is a class that extends cSimpleModule and implements the TcpSocket::ICallback interface. It has a method init to initialize the thread with a pointer to the CustomTcpServerHostApp instance and a TcpSocket instance. It also has methods established, dataArrived, handleMessage, and timerExpired to handle various events related to the socket.

CustomTcpEchoAppThread has a member variable echoAppModule, which is a pointer to the CustomTcpEchoApp instance that owns the

===================   delay and jitter   ==========================

CustomTcpEchoApp and CustomTcpEchoAppThread. CustomTcpEchoApp is a subclass of CustomTcpServerHostApp, which is itself a subclass of ApplicationBase. CustomTcpEchoApp serves as the server in a client-server communication, and it listens for incoming connections and handles them using instances of CustomTcpEchoAppThread.

CustomTcpEchoApp has several member variables that keep track of various statistics, such as the number of bytes and packets sent and received, and the average delay of received packets. It also has a method called sendDown that is used to send packets to the client, and a method called finish that is called when the simulation is complete and is used to print out various statistics about the communication.

CustomTcpEchoAppThread is a subclass of TcpServerThreadBase, and it is used to handle individual connections from clients. It has several methods that are called in response to various events, such as dataArrived, which is called when a packet is received from the client, and timerExpired, which is called when a timer expires. It also has a method called established, which is called when a connection is established with the client.

In the dataArrived method, the server calculates the delay of the received packet by looking at the packet header tag CreationTimeTag, which records the time at which the packet was created. The server also calculates the average jitter of received packets by comparing the delay of

NS3:

C++ program for simulating a network using the Network Simulator 3 (ns-3) framework. It includes various headers for different ns-3 modules and functionality, as well as some constants and macros that are used throughout the program.

There is also a template class called **SimpleHistogram** that is used for recording the frequency of different values, and a namespace containing various classes that are derived from NS3 classes. It's not clear from this snippet of code what the overall purpose of the program is or how it functions, as it seems to be just a small portion of the full program

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code is a simulation of a client-server communication over a wireless network using the ns-3 network simulator. It sets up a simulation environment with two nodes (representing the client and server), a wireless network connecting them, and a TCP/IP stack on each node.

The simulation is defined by a number of parameters, such as the client's data rate, the number and size of packets sent by the client, the start and stop times for the client and server, and the length of the simulation.

The code begins by including a number of ns-3 modules, which provide various functions for simulating networks and applications. Next, a number of constants are defined, such as CLIENT_MACHINE_NUM and SERVER_MACHINE_NUM, which represent the indices of the client and server nodes in the simulation. There are also a number of constants related to the configuration of the simulation, such as the client's data rate and the number of packets the client will send.

There is also a template class called **SimpleHistogram**, which is used to count occurrences of a particular value. This class has a std::map member variable called m_map, which stores the counts of values, and a number of methods for adding values to the histogram and printing it out.

The **namespace** ns3 contains a class called PacketCreationTimeTag, which is a subclass of the ns3::Tag class. This class is used to tag packets with the time they were created, so that the delay between when a packet is created and when it is received can be measured. The PacketCreationTimeTag class has a member variable called m_simpleValue, which stores the time a packet was created, and a number of methods for setting and getting this value, as well as for serializing and deserializing the tag.

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TcpEchoServer::HandleRead is a member function of the TcpEchoServer class that is called when there is data to be read from the socket. It reads the data from the socket and then sends it back to the sender, essentially echoing the data. This is commonly known as an "echo server" because it simply echoes back any data that it receives. The HandleRead function is using the Send method of the Socket class to send the data back to the sender.

This function reads data from the socket using the RecvFrom method of the Socket class, and then sends the data back to the sender using the Send method. It continues to do this until there are no more data to be read from the socket.

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General overview of how packets might flow in a simple network simulation using ns-3:

1. A packet is created at the source node, which is typically a client application running on a simulated host machine. The packet includes a header and a payload, which contains the data that the client wants to send to the destination node.
2. The packet is passed down through the different layers of the network stack on the source node. This includes the transport layer (e.g., TCP or UDP), the internet layer (e.g., IPv4 or IPv6), and the link layer (e.g., Ethernet or WiFi). Each layer adds its own header to the packet to provide additional information about the packet, such as the source and destination addresses, the protocol being used, and the packet size.
3. The packet is transmitted over the simulated network link, which could be a point-to-point link, a CSMA link, or a WiFi link, depending on the configuration of the simulation.
4. The packet is received by the destination node, which is typically a server application running on a simulated host machine. The packet is passed up through the different layers of the network stack on the destination node, with each layer stripping off its own header as the packet is passed up.
5. The server application processes the packet, possibly echoing it back to the client if it is an echo server, or performing some other action with the data contained in the packet.
6. The server sends a response packet back to the client, following the same process in reverse.

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In this code, packets are being sent and received over a network using the Network Simulator 3 (NS3) library. The code includes a number of NS3 modules, such as core-module, point-to-point-module, csma-module, internet-module, and applications-module, which provide various networking functionalities such as creating nodes, setting up point-to-point links, installing the internet stack on nodes, and creating application layer protocols.

The code also includes several standard C++ modules, such as map, as well as modules for WiFi networking and mobility, such as yans-wifi-helper, mobility-helper, ipv4-address-helper, and yans-wifi-channel.

There are several compile-time constants defined in the code, such as CLIENT_MACHINE_NUM, SERVER_MACHINE_NUM, CLIENT_DATA_RATE, CLIENT_PACKETS_COUNT, and CLIENT_PACKET_SIZE, which are used to specify various network parameters.

The code also defines a class called SimpleHistogram, which is used to record the frequency of different values.

Finally, the code includes a class called PacketCreationTimeTag, which is used to store meta information (a time stamp) in the header of a TCP packet. This time stamp is used to calculate the delay of the packet as it is transmitted over the network.

Overall, the flow of packets in this code can be described as follows:

1. Nodes are created and a point-to-point link is installed between them.
2. The internet stack is installed on the nodes.
3. IP addresses are assigned to the nodes.
4. A TCP echo server application is installed on the server node, and a TCP echo client application is installed on the client node.
5. The client node sends packets to the server node using the TCP echo client application.
6. The server node receives the packets and echoes them back to the client node using the TCP echo server application.
7. A packet sink application is installed on the server node to receive the echoed packets.
8. The simulation is run and statistics, such as the total number of packets received and the packet loss rate, are printed out.

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simulation of a network using the NS3 (Network Simulator 3) library. It includes various modules and headers from NS3, as well as some standard C++ headers and a custom template class called SimpleHistogram.

The code also defines several constants, such as CLIENT_MACHINE_NUM and SERVER_MACHINE_NUM, which are used as reference numbers for client and server objects in the code. There are also several constants related to logging, packet creation and transmission, and simulation parameters.

The code also includes a class called PacketCreationTimeTag, which is a type of "tag" that can be added to the header of a TCP packet. The tag stores the time at which the packet was created on the sender side, and the receiver can use this information to calculate the round-trip time for the packet.

Finally, the code includes several NS3 classes, such as TcpEchoServer and TcpEchoClient, which are used to simulate a server and client in the network. These classes define various methods, such as HandleRead and SendData, which are used to process and transmit data in the simulation. Overall, it seems that the purpose of this code is to simulate a network with a server and client, transmit data between them, and collect various statistics about the transmission.

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This code is a simulation program written in the NS3 (Network Simulator 3) framework, which is a tool for simulating the behavior of networks and communication systems. The code is written in C++ and includes a number of header files that provide various functions and classes for use in the simulation.

The first group of header files includes "ns3/core-module.h", "ns3/point-to-point-module.h", "ns3/csma-module.h", "ns3/internet-module.h", and "ns3/applications-module.h". These header files provide basic functionality for simulating networks and communication systems in NS3. The "core-module" provides core classes and functions for defining and manipulating nodes, channels, and other basic elements of a network. The "point-to-point-module" and "csma-module" provide classes and functions for simulating point-to-point and CSMA (Carrier Sense Multiple Access) networks, respectively. The "internet-module" provides classes and functions for simulating internet protocols such as IPv4 and

IPv6, and the "applications-module" provides classes and functions for simulating various types of network applications such as servers and clients.

The next group of header files includes "ns3/netanim-module.h" and "ns3/flow-monitor-module.h". These header files provide functions and classes for visualizing and monitoring the simulation. The "netanim-module" provides classes for creating animations of the simulation, and the "flow-monitor-module" provides classes for monitoring various aspects of the simulation such as flow statistics, packet size distributions, and delay statistics.

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The client and server classes in this code is implementations of the NS3 Application class, which is a class for defining network applications in NS3. These classes are used to simulate the behavior of a client and a server in a network.

The client class, called TcpEchoClient, is responsible for sending packets to the server and receiving responses from the server. It has a number of member functions and variables that are used to configure and control the client's behavior. For example, the **client** has a member function called **Setup** that is used to configure the client's parameters such as the data rate, packet size, and number of packets to send. It also has a member function called **StartApplication** that is called when the client starts sending packets to the server, and a member function called **StopApplication** that is called when the client stops sending packets.

The **server** class, called TcpEchoServer, is responsible for receiving packets from the client and sending responses back to the client. It has similar member functions and variables as the client class, including a Setup function for configuring the server's parameters and StartApplication and StopApplication functions for controlling the server's behavior. The server also has a member function called HandleRead that is called when the server receives a packet from the client. This function reads the packet, modifies it as needed (for example, by adding a delay or increasing the size of the packet), and then sends it back to the client as a response.

Overall, the client and server classes work together to simulate the behavior of a client and a server in a network. The client sends packets to the server, and the server receives and responds to these

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The TcpEchoClient class have the following methods:

- **Setup**: This function is used to configure the client's parameters such as the data rate, packet size, and number of packets to send.
- **StartApplication**: This function is called when the client starts sending packets to the server. It creates a socket and starts sending packets to the server.
- **StopApplication**: This function is called when the client stops sending packets. It closes the socket and stops sending packets.
- **SendPacket**: This function is used to send a packet to the server. It takes a packet size as an input and creates a packet with the specified size. The packet is then sent to the server using the socket created in the StartApplication function.
- **SetPacketSize**: This function is used to set the size of the packets that the client will send to the server.
- **SetPacketCount**: This function is used to set the number of packets that the client will send to the server.
- **SetDataRate**: This function is used to set the data rate at which the client will send packets to the server.
- **GetHistogram**: This function returns a histogram object that records the frequency of every packet size that the client has sent to the server.
- **GetPacketsSent**: This function returns the total number of packets that the client has sent to the server.

- **HandleRead**: This function is called when the server receives a packet from the client. It extracts the packet's creation time from the packet header and calculates the round trip time (RTT) by subtracting the current time from the packet's creation time. The server then sends an echo packet back to the client with the same size as the original packet. The echo packet is sent with a delay specified by the echo delay parameter.
- **GetHistogram**: This function returns a histogram object that records the frequency of every packet size that the server has received from the client.
- **GetPacketsReceived**: This function returns the total number of packets that the server has received from the client.
- **GetEchoedPacketsSent**: This function returns the total number of echo packets that the server has sent back to the client.

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how does **TchoClient::ScheduleTx** work?

The TcpEchoClient class have a method called ScheduleTx, which is used to schedule the transmission of packets to the server. The purpose of this method is to send a specified number of packets to the server at a fixed rate.

Here is how the **ScheduleTx** method works:

1. It first checks if the number of packets that have been sent so far is less than the total number of packets to be sent (CLIENT_PACKETS_COUNT). If all the packets have already been sent, the method returns without doing anything.
2. It creates a new packet with the specified size (CLIENT_PACKET_SIZE).
3. It attaches a tag to the packet that contains the current time. This tag is used by the server to calculate the RTT for each packet.
4. It schedules the transmission of the packet to the server at a fixed rate specified by the CLIENT_SEND_TIME parameter. This is done using the Simulator::Schedule method.
5. It increments the counter for the number of packets sent so far.
6. It calls itself again using Simulator::Schedule, with a delay specified by the CLIENT_SEND_TIME parameter. This causes the method to be called repeatedly, sending packets to the server at a fixed rate.

The ScheduleTx method is called by the StartApplication method, which is called when the client starts sending packets to the server. This causes the client to send a specified number of packets to the server at a fixed rate until the StopApplication method is called, which stops the client from sending any more packets.

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Here is a detailed explanation of the other methods in the TcpEchoClient class:

TcpEchoClient::TcpEchoClient()

- This is the constructor for the TcpEchoClient class. It initializes the instance variables for the object with default values.

TcpEchoClient::Setup()

- This method sets up the client machine node and creates an object for the TCP socket that will be used to send data to the server. It also sets up the event handler for when the socket is connected to the server.

TcpEchoClient::SendPacket()

- This method sends a packet to the server. It creates a new packet with the specified size and adds a tag to it with the current simulation time. It then sends the packet through the socket.

TcpEchoClient::ConnectionSucceeded()

- This method is called when the socket successfully connects to the server. It sets up the event handler for when the socket receives data and starts sending packets to the server.

TcpEchoClient::ConnectionFailed()

- This method is called when the socket fails to connect to the server. It logs an error message and stops the simulation.

TcpEchoClient::DataReceived()

- This method is called when the socket receives data from the server. It reads the data from the packet and logs the packet size and delay. It also updates the histogram for the packet size.

TcpEchoClient::ScheduleTx()

- This method schedules the next packet transmission. It calculates the interval between packet transmissions based on the data rate and packet size, and schedules the next transmission with this interval. It also checks if the maximum number of packets has been reached, and stops the simulation if necessary.

TcpEchoClient::StopApplication()

- This method stops the client application. It closes the socket and cancels any scheduled packet transmissions.

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<u>Execution order :</u>

1. The client first initiates the process by calling the TcpEchoClient::StartApplication method. This method sets up the client's socket, binds it to an address and port, and starts the process of sending data to the server.
2. The client then calls the TcpEchoClient::ScheduleTx method to schedule the transmission of a packet to the server. This method creates a new packet with a specified size and sends it to the server using the client's socket.

3. When the server receives the packet, it calls the TcpEchoServer::HandleRead method to handle the incoming packet. This method extracts the data from the packet, and if the server is configured to echo the data back to the client, it creates a new packet with the same data and sends it back to the client.
4. When the client receives the echoed packet, it calls the TcpEchoClient::HandleRead method to handle the incoming packet. This method extracts the data from the packet and compares it to the data that was originally sent to the server. If the data matches, it increments a counter to keep track of the number of successful echo replies received.
5. The process repeats until the client has sent all of the packets that it was configured to send, or until the simulation time has reached the specified stop time.

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<u>The execution order of the server methods</u> when a packet is being sent and then echoed would be as follows:

1. The StartApplication method of the TcpEchoServer class is called, which initializes the server and sets it up to listen for incoming connections.
2. The ConnectionSucceeded event is triggered when a client successfully connects to the server.
3. The ConnectionSucceeded event handler calls the Accept method of the TcpEchoServer class to accept the incoming connection and create a TcpSocket object for it.
4. The Accept method also sets up a callback function for the NewConnectionCreated event, which is triggered whenever a new connection is created.
5. The NewConnectionCreated event handler calls the StartRx method of the TcpEchoServer class, which sets up a callback function for the DataArrived event.
6. The DataArrived event is triggered whenever data is received on the socket.
7. The DataArrived event handler calls the HandleRead method of the TcpEchoServer class, which reads the data from the socket and echoes it back to the client.
8. The HandleRead method also updates the m_totalRx variable to keep track of the total amount of data received from the client.
9. The HandleRead method calls the ScheduleTx method to schedule the next transmission of data to the client.
10. The ScheduleTx method sets up a timer to trigger the SendData method at a later time.
11. The SendData method is called when the timer expires, and it sends the data to the client using the Send method of the TcpSocket class.

12. The Send method sends the data to the client and updates the m_totalTx variable to keep track of the total amount of data sent to the client.
13. The process continues until the StopApplication method is called, which stops the server and closes all connection

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<u>Here is the method execution order when a packet is sent by the client and received by the server, then echoed by the server and received by the client:</u>

1. TcpEchoClient::StartApplication
2. TcpEchoClient::Connect
3. TcpEchoClient::SendPacket
4. TcpEchoClient::ConnectionSucceeded
5. TcpEchoClient::ConnectionFailed
6. TcpEchoServer::StartApplication
7. TcpEchoServer::ConnectionSucceeded
8. TcpEchoServer::ConnectionFailed
9. TcpEchoServer::HandleRead
10. TcpEchoServer::SendPacket
11. TcpEchoClient::HandleRead
12. TcpEchoClient::StopApplication
13. TcpEchoServer::StopApplication

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1. TcpEchoClient::StartApplication: called when the client application is started
2. TcpEchoClient::SendPacket: called when the client sends a packet to the server
3. TcpEchoServer::StartApplication: called when the server application is started
4. TcpEchoServer::HandleRead: called when the server receives a packet from the client
5. TcpEchoServer::EchoPacket: called when the server echoes the received packet back to the client
6. TcpEchoClient::HandleRead: called when the client receives a packet from the server (the echoed packet)
7. TcpEchoClient::HandleSuccess: called when the client successfully receives the echoed packet
8. TcpEchoClient::ScheduleTx: called to schedule the next packet transmission from the client
9. TcpEchoServer::HandleSuccess: called when the server successfully echoes the packet back to the client

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the list of method execution in the order that they would be called, along with a description of the conditions under which each method is called:

1. TcpEchoClient::StartApplication: This method is called when the client application is started, which happens at the time specified by the CLIENT_START_TIME define. This method sets up the client socket and schedules the first packet transmission.
2. TcpEchoClient::SendPacket: This method is called when it is time for the client to send a new packet. This happens at the interval specified by the CLIENT_SEND_TIME define. This method sends the packet using the client socket, and also schedules the next packet transmission.
3. TcpEchoServer::StartApplication: This method is called when the server application is started, which happens at the time specified by the SERVER_START_TIME define. This method sets up the server socket and starts listening for incoming connections.
4. TcpEchoServer::ConnectionSucceeded: This method is called when the server socket successfully establishes a connection with the client socket.
5. TcpEchoServer::HandleRead: This method is called when the server socket receives a packet from the client. This method echoes the packet back to the client, according to the SERVER_ECHO_FACTOR and SERVER_ECHO_DELAY defines.
6. TcpEchoClient::HandleRead: This method is called when the client socket receives a packet from the server. This method checks if the packet is the expected echo of a packet that was previously sent by the client, and updates the appropriate statistics.
7. TcpEchoClient::StopApplication: This method is called when the client application is stopped, which happens at the time specified by the CLIENT_STOP_TIME define. This method closes the client socket and stops the packet transmission

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complete list of method execution in the order they are called when a packet is sent by the client and received by the server, then echoed by the server and received by the client:

1. TcpEchoClient::StartApplication: This method is called when the client application is started, typically at the beginning of the simulation. It creates and schedules the first packet transmission using the ScheduleTx method.

2. TcpEchoClient::ScheduleTx: This method is called to schedule the transmission of a new packet. It sets up the packet with the appropriate size and payload, and sends it using the socket's Send method.
3. TcpEchoServer::StartApplication: This method is called when the server application is started, typically at the beginning of the simulation. It creates a socket and binds it to the server's IP address and port number.
4. TcpEchoServer::HandleAccept: This method is called when the server's socket receives a new incoming connection request from a client. It creates a new socket and accepts the connection, allowing data to be exchanged between the client and server.
5. TcpEchoServer::HandleRead: This method is called when the server's socket receives a new packet from the client. It reads the packet and checks if it contains a PacketCreationTimeTag. If it does, it calculates the round trip time (RTT) by comparing the current time to the packet creation time. The server then echoes the packet back to the client by calling the socket's Send method.
6. TcpEchoClient::HandleRead: This method is called when the client's socket receives a new packet from the server. It reads the packet and compares its size to the expected size. If the sizes match, the client increments the received packet count. If the received packet count equals the total number of packets expected,

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the list of method execution when a packet is sent by the client and received by the server, then echoed by the server and received by the client:

1. TcpEchoClient::StartApplication: called when the client application is started
2. TcpEchoClient::Connect: called to initiate a connection to the server
3. TcpEchoClient::ConnectionSucceeded: called when the connection to the server is established
4. TcpEchoClient::SendData: called to send data to the server
5. TcpEchoServer::StartApplication: called when the server application is started
6. TcpEchoServer::HandleConnection: called when a new connection is established with the client
7. TcpEchoServer::HandleRead: called when data is received from the client
8. TcpEchoServer::EchoData: called to echo the data back to the client
9. TcpEchoServer::HandleWrite: called to write the echoed data back to the client
10. TcpEchoClient::HandleRead: called when data is received from the server (the echoed data)

The conditions under which these methods are called are as follows:

- TcpEchoClient::StartApplication: called when the client application is started, either manually or through the Simulator::Schedule method

- TcpEchoClient::Connect: called when the client application is started and a connection to the server needs to be established
- TcpEchoClient::ConnectionSucceeded: called when the connection to the server is established, indicated by a successful return value from the TcpSocket::Connect method
- TcpEchoClient::SendData: called when the client wants to send data to the server, either manually or through the Simulator::Schedule method
- TcpEchoServer::StartApplication: called when the server application is started, either manually or through the Simulator::Schedule method
- TcpEchoServer::HandleConnection: called when a new connection is established with the client, indicated by a successful return value from the TcpSocket::Accept method
- TcpEchoServer::HandleRead: called when data is received from the client, indicated by a successful return value from the TcpSocket::Recv method
- TcpEchoServer::EchoData: called to echo the data back to the client
- TcpEchoServer::HandleWrite: called to write the echoed data back to the client, indicated by a successful return value from the TcpSocket::Send method
- TcpEchoClient::HandleRead: called when data is received from the server (the echoed data), indicated by a successful return value from the TcpSocket::Recv method

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One aspect of the code that stands out is the use of the PacketCreationTimeTag class, which is used to attach a timestamp to packets as they are created. This is done in the TcpEchoClient::CreatePacket method, where a new PacketCreationTimeTag object is created and attached to the packet using the AddPacketTag method:

```
PacketCreationTimeTag tag;

tag.SetSimpleValue(Simulator::Now().GetSeconds());

packet->AddPacketTag(tag);
```

The PacketCreationTimeTag class is derived from the Tag class, which is part of the ns-3 library and provides a way to attach metadata to packets. The Tag class has several pure virtual methods that must be implemented by any derived classes, including GetTypeId, GetInstanceTypeId, GetSerializedSize, Serialize, Deserialize, and Print. These methods are used to serialize and deserialize the tag data and to perform other operations on the tag.

The PacketCreationTimeTag class adds a single member variable, m_simpleValue, which is used to store the timestamp value. It also provides SetSimpleValue and GetSimpleValue methods to set and retrieve the value of this member variable.

Once the PacketCreationTimeTag has been attached to the packet, it can be retrieved later using the GetPacketTag method, as is done in the TcpEchoServer::HandleRead method:

```
PacketCreationTimeTag tag;

packet->PeekPacketTag(tag);

double creationTime = tag.GetSimpleValue();
```

The PacketCreationTimeTag is used in this code to measure the round-trip time (RTT) of packets sent between the client and server. When the client sends a packet, it includes the current time as a timestamp in the tag. When the server receives the packet, it retrieves the timestamp from the tag and calculates the RTT by subtracting the timestamp from the current time. This RTT value is then logged to the console.

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how is echoing implemented

In the provided code, echoing is implemented by the TcpEchoServer class. When the server receives a packet from a client, it creates a new packet with the same data as the received packet and sends it back to the client. This process is referred to as echoing because the server is simply sending back the data that it received from the client.

Echoing is implemented in the TcpEchoServer class by the HandleRead method. This method is called when the server receives a packet from a client. The method first creates a new packet with the same data as the received packet, using the Create<Packet> method and the data from the received packet. It then sends the new packet back to the client using the Send method.

The echoing process is repeated for each packet received by the server until the client stops sending packets or the simulation ends. The echoing process is triggered by the reception of packets from the client, and the server continues to echo packets back to the client until there are no more packets to be received.

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callback functions that are registered with various objects in the ns-3 simulation. They are called at specific points in the simulation, such as when a packet is transmitted, dropped, or received.

For example, the "ClientMacTxDrop" function is registered as a callback for when a packet is dropped due to an error in the MAC layer of the client. Similarly, the "ClientIpV4L3SendOutgoingCallback" function is called whenever a packet is transmitted by the client's IPv4 layer.

The "getAddress" function is a template function that takes a function object as an argument and returns the memory address of the function. This is done by using the "target" method of the std::function object to get a pointer to the function, and then returning the value of the pointer as an integer.

The variables "ClientIpV4L3SendOutGoingCount", "ClientIpV4L3STxCount", "ServerIpV4L3SendOutGoingCount", and "ServerIpV4L3STxCount" are all counters that are incremented each time the corresponding callback function is called. They are used to track how many times the corresponding event occurs during the simulation.

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This code defines several callback functions, which are essentially functions that are called when a specific event occurs. The purpose of these callback functions is to log or record information about the event when it happens.

- The ServerMacTxDrop callback function is called when a packet is dropped during transmission at the MAC layer on the server side. It logs a message indicating that the packet was dropped at the current simulation time.
- The ServerPhyTxDrop callback function is called when a packet is dropped during transmission at the PHY layer on the server side. It logs a message indicating that the packet was dropped at the current simulation time.

- The ServerPhyRxDrop callback function is called when a packet is dropped during reception at the PHY layer on the server side. It logs a message indicating that the packet was dropped at the current simulation time.
- The ClientMacTxDrop callback function is called when a packet is dropped during transmission at the MAC layer on the client side. It logs a message indicating that the packet was dropped at the current simulation time.
- The ClientPhyTxDrop callback function is called when a packet is dropped during transmission at the PHY layer on the client side. It logs a message indicating that the packet was dropped at the current simulation time.
- The ClientPhyRxDrop callback function is called when a packet is dropped during reception at the PHY layer on the client side. It logs a message indicating that the packet was dropped at the current simulation time.
- The SocketRxDrop callback function is called when a packet is dropped during reception at the socket level. It logs a message indicating that the packet was dropped at the current simulation time.
- The IpV4L3DropPkt callback function is called when a packet is dropped during transmission or reception at the IP layer. It logs a message indicating the reason for the packet drop, as well as the current simulation time.

These callback functions are typically called by the corresponding

ServerMacTxDrop is a callback function that is called when a packet is dropped due to an error during transmission at the MAC layer on the server side. The function simply logs a message indicating that the drop occurred at the current simulation time.

ServerPhyTxDrop is similar to ServerMacTxDrop, but is called when a packet is dropped due to an error during transmission at the PHY layer on the server side.

ServerPhyRxDrop is called when a packet is dropped due to an error during reception at the PHY layer on the server side.

ClientMacTxDrop, ClientPhyTxDrop, and ClientPhyRxDrop are the corresponding callback functions for the client side, and are called when a packet is dropped due to an error during transmission or reception at the MAC or PHY layer on the client side.

SocketRxDrop is a callback function that is called when a packet is dropped due to an error during reception at the socket level.

IpV4L3DropPkt is called when a packet is dropped by the IPv4 layer on either the client or server side. The function logs the reason for the drop and the current simulation time.

ClientIpV4L3SendOutgoingCallback and ServerIpV4L3SendOutgoingCallback are callback functions that are called whenever a packet is sent by the IPv4 layer on the client or server side, respectively. They increment a counter variable to track the number of packets sent.

ClientIpV4L3TX and ServerIpV4L3TX are callback functions that are called whenever a packet is transmitted by the IPv4 layer on the client or server side, respectively. They also increment a counter