acknowledgment (Acknowledgement, ACK), the TCP transmit end sends two more packets. After ACKs of the two packets are received, the Cwnd increases to four packets. In this way, each time an ACK of one packet is received, a value of the Cwnd increases by one packet.

[0006] In a conventional network, because routing paths and network statuses between two communication nodes change constantly, algorithms regarding how a single node detects a network status in the TCP protocol evolve constantly. Due to inflexibility of a network, bandwidths are not fully utilized, and because of contention between TCP transmission nodes, throughputs are all at low levels.

[0007] In some distributed computing applications, data needs to be efficiently transmitted between two computing nodes within a particular period of time. Therefore, TCP-based optimization becomes increasingly important. Software-defined networking (Software Defined Networking, SDN) provides application-based management and control capabilities, so that SDN-based TCP optimization also becomes increasingly important.

SUMMARY

[0008] In view of this, embodiments of the present invention provide a data transmission method, apparatus, and system, so as to optimize TCP data transmission in an SDN network.

[0009] According to a first aspect, the present invention provides a data transmission method, applied to software-defined networking SDN, where a controller in the SDN network is connected to a switching device through a southbound interface and is connected to an application server through a northbound interface, at least one application runs on the application server, and when the application server determines that currently data needs to be transmitted from a sending device to a receiving device by using the Transmission Control Protocol TCP, the method includes:

receiving, by the controller, a TCP transmission resource allocation request from the application server, where the TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device;

determining, by the controller, a first transmission path and a second transmission path according to the TCP transmission resource allocation request, where the first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device; and

sending, by the controller, a TCP transmission resource allocation response message to the application server, where the TCP transmission resource allocation response message includes bandwidth information of the first transmission path and a TCP round-trip transmission delay, the

TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path, and the bandwidth information of the first transmission path and the TCP round-trip transmission delay are used to determine an initial value of a transmit window for TCP data transmission between the sending device and the receiving device.

[0010] With reference to the first aspect, in a first possible implementation manner, before the sending, by the controller, a TCP transmission resource allocation response message to the application server, the method further includes: obtaining, by the controller, a transmission delay of the first transmission path and a transmission delay of the second transmission path, and determining the TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path, where the TCP round-trip transmission delay is positively correlated with a sum of the transmission delay of the first transmission path and the transmission delay of the second transmission path.

[0011] With reference to the first aspect or the foregoing possible implementation manner, in a second possible implementation manner, before the sending, by the controller, a TCP transmission resource allocation response message to the application server, the method further includes: determining, by the controller, a packet loss rate of the first transmission path, and

in this case, the TCP transmission resource allocation response message further includes the packet loss rate of the first transmission path.

[0012] With reference to any one of the first aspect or the foregoing possible implementation manners, in a third possible implementation manner, the TCP transmission resource allocation request further carries maximum transmission unit MTU value information, and the MTU value information includes a maximum value for an MTU value of the sending device and a maximum value for an MTU value of the receiving device;

the method further includes: determining, by the controller according to the MTU value information in the TCP transmission resource allocation request, an MTU value used by the first transmission path to transmit the data, where the MTU value used by the first transmission path to transmit the data is not greater than a smaller value between the maximum value for the MTU value of the sending device and the maximum value for the MTU value of the receiving device; and

in this case, the TCP transmission resource allocation response message further includes the MTU value used by the first transmission path to transmit the data.

[0013] With reference to any one of the first aspect or the foregoing possible implementation manners, in a fourth possible implementation manner, the TCP transmission resource allocation

request further includes a bandwidth required for transmitting the data; and

the determining, by the controller, a first transmission path according to the TCP transmission resource allocation request includes: selecting, according to a network topology of the switching device and from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data as the first transmission path.

[0014] With reference to any one of the first aspect or the foregoing possible implementation manners, in a fifth possible implementation manner, the selecting, by the controller from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data as the first transmission path includes: selecting, by the controller, from all paths whose remaining bandwidth resources meet the requirement for transmitting the data between the sending device and the receiving device, a path whose remaining bandwidth resources are the fewest or a path whose hop count is the smallest as the first transmission path.

[0015] According to a second aspect, the present invention provides a controller, applied to software-defined networking SDN, where the controller is connected to a switching device through a southbound interface and is connected to an application server through a northbound interface, and the controller includes: a processor, a memory, a bus, and a communications interface, where

the memory is configured to store an instruction executable by a computing device, the processor and the memory are connected through the bus, and when the computing device operates, the processor executes the instruction that is executable by the computing device and that is stored in the memory, to enable the computing device to perform the method according to any one of the first aspect or the possible implementation manners of the first aspect.

[0016] According to a third aspect, the present invention provides a data transmission method, applied to software-defined networking SDN, where a controller in the SDN network is connected to a switching device through a southbound interface and is connected to an application server through a northbound interface, at least one application runs on the application server, and when the application server determines that currently data needs to be transmitted from a sending device to a receiving device by using the TCP protocol, the method includes:

sending, by the application server, a TCP transmission resource allocation request to the controller, where the TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device;

receiving, by the application server, a TCP transmission resource allocation response

message from the controller, where the TCP transmission resource allocation response message includes a bandwidth of the first transmission path and a TCP round-trip transmission delay, the TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path, the first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device; and

determining, by the application server according to the bandwidth of the first transmission path and the TCP round-trip transmission delay, an initial value of a transmit window for TCP data transmission between the sending device and the receiving device.

[0017] With reference to the third aspect, in a first possible implementation manner, the initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0018] With reference to the third aspect or the foregoing possible implementation manner, in a second possible implementation manner, the TCP transmission resource allocation response message further carries a packet loss rate of the first transmission path; and

the method further includes: determining, by the application server, the initial value of the transmit window according to the packet loss rate, where the initial value of the transmit window is negatively correlated with the packet loss rate.

[0019] With reference to any one of the third aspect or the foregoing possible implementation manners, in a third possible implementation manner, the method further includes: determining, by the application server, an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path and the TCP round-trip transmission delay, where the initial value of the receive window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0020] With reference to any one of the third aspect or the foregoing possible implementation manners, in a fourth possible implementation manner, the method further includes: determining, by the application server, an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path, the TCP round-trip transmission delay, and the packet loss rate, where the initial value of the receive window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately and is negatively correlated with the packet loss rate.

[0021] With reference to any one of the third aspect or the foregoing possible implementation

TCP round-trip transmission delay.

[0028] With reference to any one of the third aspect or the foregoing possible implementation manners, in a twelfth possible implementation manner, the method further includes: sending, by the application server, an acknowledgment wait time setting message to the receiving device, where the acknowledgment wait time setting message includes the acknowledgment wait time.

[0029] According to a fourth aspect, the present invention provides an application server, applied to software-defined networking SDN, where a controller of the SDN is connected to a switching device through a southbound interface and is connected to the application server through a northbound interface, and the application server includes: a processor, a memory, a bus, and a communications interface, where

the memory is configured to store an instruction executable by a computing device, the processor and the memory are connected through the bus, and when the computing device operates, the processor executes the instruction that is executable by the computing device and that is stored in the memory, to enable the computing device to perform the method according to any one of the third aspect or the possible implementation manners of the third aspect.

[0030] According to a fifth aspect, the present invention provides a data transmission method, applied to software-defined networking SDN, where a controller in the SDN network is connected to a switching device through a southbound interface and is connected to an application server through a northbound interface, at least one application runs on the application server, and when the application server determines that currently data needs to be transmitted from a sending device to a receiving device by using the TCP protocol, the method includes:

receiving, by the sending device, a transmit window setting message, where the transmit window setting message includes an initial value of a transmit window of the sending device; and

performing, by the sending device, TCP data transmission according to the initial value of the transmit window.

[0031] With reference to the fifth aspect, in a first possible implementation manner, the sending device is further configured to: receive a maximum transmission unit MTU setting message, where the MTU setting message includes an MTU value of the sending device during data transmission; and set an MTU value of the sending device according to an indication of the MTU setting message.

[0032] With reference to the fifth aspect or the foregoing possible implementation manner, in a second possible implementation manner, the sending device is further configured to: receive a retransmission timeout interval setting message, where the retransmission timeout interval setting message includes a retransmission timeout interval value used by the sending device during TCP

data transmission; and set the retransmission timeout interval value of the sending device according to an indication of the retransmission timeout interval setting message.

[0033] According to a sixth aspect, the present invention provides a computing device, applied to software-defined networking SDN, where a controller of the SDN is connected to a switching device through a southbound interface and is connected to an application server through a northbound interface, the application server is configured to control data to be sent from the computing device to a receiving device, and the computing device includes: a processor, a memory, a bus, and a communications interface, where

the memory is configured to store an instruction executable by the computing device, the processor and the memory are connected through the bus, and when the computing device operates, the processor executes the instruction that is executable by the computing device and that is stored in the memory, to enable the computing device to perform the method according to any one ofthe fifth aspect or the foregoing possible implementation manners of the fifth aspect.

[0034] According to a seventh aspect, the present invention provides a data transmission apparatus, applied to software-defined networking SDN, where a controller of the SDN is connected to a switching device through a southbound interface and is connected to an application server through a northbound interface, the application server is configured to control data to be sent from the apparatus to a receiving device, and the data transmission apparatus includes:

a receiving unit, configured to receive a transmit window setting message, where the transmit window setting message includes an initial value of a transmit window of the data transmission device; and

a sending unit, configured to perform TCP data transmission according to the initial value of the transmit window.

[0035] With reference to the seventh aspect, in a first possible implementation manner, the receiving unit is further configured to receive a maximum transmission unit MTU setting message, where the MTU setting message includes an MTU value of the data transmission device during data transmission.

[0036] With reference to the seventh aspect or the foregoing possible implementation manner, in a second possible implementation manner, the receiving unit is further configured to receive a retransmission timeout interval setting message, where the retransmission timeout interval setting message includes a retransmission timeout interval value of the data transmission device during TCP data transmission.

[0037] According to an eighth aspect, the present invention provides a data

transmission apparatus, applied to software-defined networking SDN, where the apparatus is connected to a switching device through a southbound interface and is connected to an application server through a northbound interface, the application server is configured to control data to be sent from a sending device to a receiving device, and the apparatus includes:

a receiving unit, configured to receive a TCP transmission resource allocation request from the application server, where the TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device;

a determining unit, configured to determine a first transmission path and a second transmission path according to the TCP transmission resource allocation request, where the first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device; and

a sending unit, configured to send a TCP transmission resource allocation response message to the application server, where the TCP transmission resource allocation response message includes bandwidth information of the first transmission path and a TCP round-trip transmission delay, the TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path, and the bandwidth information of the first transmission path and the TCP round-trip transmission delay are used to determine an initial value of a transmit window for TCP data transmission between the sending device and the receiving device.

[0038] With reference to the eighth aspect, in a first possible implementation manner, the determining unit is further configured to: obtain a transmission delay of the first transmission path and a transmission delay of the second transmission path; and determine the TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path, where the TCP round-trip transmission delay is positively correlated with a sum of the transmission delay of the first transmission path and the transmission delay of the second transmission path.

[0039] With reference to the eighth aspect or the foregoing possible implementation manner, in a second possible implementation manner, the determining unit is further configured to determine a packet loss rate of the first transmission path; and

in this case, the TCP transmission resource allocation response message further includes the packet loss rate of the first transmission path.

[0040] With reference to any one of the eighth aspect or the foregoing possible implementation

manners, in a third possible implementation manner, the TCP transmission resource allocation request further carries maximum transmission unit MTU value information, and the MTU value information includes a maximum value for an MTU value of the sending device and a maximum value for an MTU value of the receiving device;

the determining unit is further configured to determine, according to the MTU value information in the TCP transmission resource allocation request, an MTU value used by the first transmission path to transmit the data, where the MTU value used by the first transmission path to transmit the data is not greater than a smaller value between the maximum value for the MTU value of the sending device and the maximum value for the MTU value of the receiving device; and

in this case, the TCP transmission resource allocation response message further includes the MTU value used by the first transmission path to transmit the data.

[0041] With reference to any one of the eighth aspect or the foregoing possible implementation manners, in a fourth possible implementation manner, the TCP transmission resource allocation request further includes a bandwidth required for transmitting the data; and

the determining unit being configured to determine a first transmission path according to the TCP transmission resource allocation request includes: selecting, by the determining unit according to a network topology of the switching device and from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data as the first transmission path.

[0042] With reference to any one of the eighth aspect or the foregoing possible implementation manners, in a fifth possible implementation manner, the selecting, from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data as the first transmission path includes: selecting, by the determining unit, from all paths whose remaining bandwidth resources meet the requirement for transmitting the data between the sending device and the receiving device, a path whose remaining bandwidth resources are the fewest or a path whose hop count is the smallest as the first transmission path.

[0043] According to a ninth aspect, the present invention provides a data transmission apparatus, applied to software-defined networking SDN, where a controller in the SDN network is connected to a switching device through a southbound interface and is connected to the apparatus through a northbound interface, at least one application runs on the apparatus, the apparatus is configured to control data to be sent from a sending device to a receiving device, and the apparatus includes:

a sending unit, configured to send a TCP transmission resource allocation request to the controller, where the TCP transmission resource allocation request carries an address of the sending

device and an address of the receiving device;

a receiving unit, configured to receive a TCP transmission resource allocation response message from the controller, where the TCP transmission resource allocation response message includes a bandwidth of the first transmission path and a TCP round-trip transmission delay, the TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path, the first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device; and

a determining unit, configured to determine, according to the bandwidth of the first transmission path and the TCP round-trip transmission delay, an initial value of a transmit window for TCP data transmission between the sending device and the receiving device, where the initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0044] With reference to the ninth aspect, in a first possible implementation manner, the initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0045] With reference to the ninth aspect or the foregoing possible implementation manner, in a second possible implementation manner, the TCP transmission resource allocation response message further carries a packet loss rate of the first transmission path; and

the determining unit is further configured to determine the initial value of the transmit window according to the packet loss rate, where the initial value of the transmit window is negatively correlated with the packet loss rate.

[0046] With reference to any one of the ninth aspect or the foregoing possible implementation manners, in a third possible implementation manner, the determining unit is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path and the TCP round-trip transmission delay, where the initial value of the receive window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0047] With reference to any one of the ninth aspect or the foregoing possible implementation manners, in a fourth possible implementation manner, the determining unit is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path, the TCP round-trip transmission delay, and the packet loss rate, where

[0054] With reference to any one of the ninth aspect or the possible implementation manners, in an eleventh possible implementation manner, the determining unit is further configured to determine an acknowledgment wait time of the receiving device according to the TCP round-trip transmission delay, where the acknowledgment wait time is positively correlated with the TCP round-trip transmission delay.

[0055] With reference to any one of the ninth aspect or the foregoing possible implementation manners, in a twelfth possible implementation manner, the sending unit is further configured to send an acknowledgment wait time setting message to the receiving device, where the acknowledgment wait time setting message includes the acknowledgment wait time.

[0056] According to a tenth aspect, the present invention provides a data transmission system, applied to software-defined networking SDN, and including an application server, a controller, a sending device, a receiving device, and a switching device, where the controller in the SDN network is connected to a switching device through a southbound interface and is connected to the application server through a northbound interface, at least one application runs on the application server, and the application server is configured to control data to be sent from the sending device to the receiving device;

the application server is configured to send a TCP transmission resource allocation request to the controller, where the TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device;

the controller is configured to: determine a first transmission path and a second transmission path according to the TCP transmission resource allocation request, where the first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device; and send a TCP transmission resource allocation response message to the application server, where the TCP transmission resource allocation response message includes bandwidth information of the first transmission path and a TCP round-trip transmission delay, and the TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path;

the application server is further configured to: determine, according to a bandwidth of the first transmission path and the TCP round-trip transmission delay, an initial value of a transmit window for TCP data transmission between the sending device and the receiving device; and send a transmit window setting message to the sending device, where the transmit window setting message

includes the initial value of the transmit window; and

the sending device is configured to: set a size of the transmit window to the initial value of the transmit window according to the transmit window setting message; and perform TCP data transmission.

[0057] With reference to the tenth aspect, in a first possible implementation manner, the initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0058] With reference to the tenth aspect or the foregoing possible implementation manner, in a second possible implementation manner, the controller is further configured to: obtain a transmission delay of the first transmission path and a transmission delay of the second transmission path; and determine the TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path, where the TCP round-trip transmission delay is positively correlated with a sum of the transmission delay of the first transmission path and the transmission delay of the second transmission path.

[0059] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in a third possible implementation manner, the controller is further configured to determine a packet loss rate of the first transmission path; and

in this case, the TCP transmission resource allocation response message further includes the packet loss rate of the first transmission path.

[0060] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in a fourth possible implementation manner, the application server is further configured to determine the initial value of the transmit window according to the packet loss rate, where the initial value of the transmit window is negatively correlated with the packet loss rate.

[0061] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in a fifth possible implementation manner, the application server is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path and the TCP round-trip transmission delay, where the initial value of the receive window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0062] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in a sixth possible implementation manner, the application server is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path, the TCP round-trip transmission delay, and the packet loss rate, where the initial value of the receive window is positively correlated with the bandwidth of the first

transmission path and the TCP round-trip transmission delay separately and is negatively correlated with the packet loss rate.

[0063] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in a seventh possible implementation manner, the application server is further configured to send a receive window setting message to the receiving device, where the receive window setting message includes the initial value of the receive window; and

the receiving device is configured to: set a size of the receive window to the initial value of the receive window according to an indication of the receive window setting message, and perform TCP data transmission.

[0064] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in an eighth possible implementation manner, the TCP transmission resource allocation request further carries maximum transmission unit MTU value information, and the MTU value information is used to indicate a maximum value for an MTU value of the sending device and a maximum value for an MTU value of the receiving device;

the controller is further configured to determine, according to the MTU value information in the TCP transmission resource allocation request, an MTU value used by the first transmission path to transmit the data, where the MTU value used by the first transmission path to transmit the data is not greater than a smaller value between the maximum value for the MTU value of the sending device and the maximum value for the MTU value of the receiving device; and

the TCP transmission resource allocation response message further includes the MTU value used by the first transmission path to transmit the data.

[0065] With reference to any one of the tenth aspect or the foregoing implementation manners, in a ninth possible implementation manner, the application server is further configured to: determine that the MTU values of the sending device and the receiving device are the MTU value used by the first transmission path to transmit the data; and send an MTU setting message to the sending device and the receiving device, where the MTU setting message includes the MTU value for the first transmission path.

[0066] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in a tenth possible implementation manner, the application server is further configured to: determine a retransmission timeout interval of the sending device according to the TCP round-trip transmission delay, where the retransmission timeout interval is positively correlated with the TCP round-trip transmission delay; and send a retransmission timeout interval setting message to the sending device, where the retransmission timeout interval setting message includes the retransmission timeout interval.

[0067] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in an eleventh possible implementation manner, the application server is further configured to: determine an acknowledgment wait time of the receiving device according to the TCP round-trip transmission delay, where the acknowledgment wait time is positively correlated with the TCP round-trip transmission delay; and send an acknowledgment wait time setting message to the receiving device, where the acknowledgment wait time setting message includes the acknowledgment wait time.

[0068] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in a twelfth possible implementation manner, the TCP transmission resource allocation request further includes a bandwidth required for transmitting the data; and

the determining, by the controller, a first transmission path according to the TCP transmission resource allocation request includes: selecting, according to a network topology of the switching device and from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data as the first transmission path.

[0069] With reference to any one of the tenth aspect or the foregoing possible implementation manners, in a thirteenth possible implementation manner, the selecting, by the controller from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data as the first transmission path includes: selecting, by the controller, from all paths whose remaining bandwidth resources meet the requirement for transmitting the data between the sending device and the receiving device, a path whose remaining bandwidth resources are the fewest or a path whose hop count is the smallest as the first transmission path.

[0070] According to the technical solutions provided in the present invention, a slow start process of TCP can be bypassed by setting an initial size of a transmit window for TCP data transmission. In addition, an initial value of the transmit window is determined according to a bandwidth of a data transmission path and a TCP round-trip time. Therefore, transmission can be performed with a relatively high throughput, and a prior-art problem is avoided that halved oscillation of a sliding window caused by repeated network detection eventually affects a network throughput.

BRIEF DESCRIPTION OF DRAWINGS

[0071] To describe the technical solutions in the embodiments of the present invention more clearly, the following briefly introduces the accompanying drawings required for describing the

includes different network services and applications. The controller 108 is located at a control layer of the SDN network, and is a logical control center of the SDN network. The controller 108 is connected to the switching device 106 through a southbound interface, provides a network instruction, maintains a network topology, controls data forwarding by the switching device 106, or the like. The controller 108 is further connected to the application server 110 through a northbound interface. The switching device 106 is located at a data forwarding layer of the SDN network, and is responsible for data processing, forwarding, status collection, or the like. The computing device 104 is a host running in a data center network, and data may be transmitted between computing devices 104 by using the TCP protocol.

[0084] The network 102 may be the Internet, an intranet, a local area network (Local Area Network, LAN for short), a wide area network (Wide Area Network, WAN for short), a storage area network (Storage Area Network, SAN for short), or the like, or a combination of the foregoing networks.

[0085] An objective of FIG. 1 is to introduce participants of TCP data transmission in the data center and relationships between the participants. Therefore, the described SDN data center environment 100 is greatly simplified. Because some aspects of the SDN data center network are common knowledge in the art, these aspects such as authentication schemes and security are not described in detail herein.

[0086] The application server 110, the controller 108, the sending device 104, or the receiving device 104 in FIG. 1 may have any structure. FIG. 2 is a block diagram generally showing an example of a system of a computing device 200 that is applicable to the application server 110, the controller 108, the sending device 104, or the receiving device 104 in FIG. 1. The implementation device system in FIG. 2 is merely an example, and is not intended to impose any limitation on the scope of application or functions of this embodiment of the present invention, and the application server 110, the controller 108, the sending device 104, or the receiving device 104 should not be explained as having any dependence or requirement related to any one or a combination of the components shown in FIG. 2.

[0087] The computing device 200 includes one storage module 202, one storage controller 216, one or more processors (CPUs) 218, one peripheral interface 220, and one peripheral port 214. These components communicate with each other through one or more communications buses or signal cables 212. The computing device 200 may be any electronic communications device, including, but not limited to, a portable computer, a personal desktop computer, a tablet computer, a mobile phone, a personal digital assistant (PDA), a server, a multiprocessor system, a microprocessor-based system, a set top box, a programmable consumer appliance, a network PC, a

micro-computer, a mainframe computer, and a distributed computing environment that includes any one of the foregoing systems or devices. The computing device 200 in FIG. 2 is merely an example of the computing device 200. The computing device 200 may include more or fewer components than those shown in FIG. 2, or may have a different component configuration manner. The components shown in FIG. 2 may be implemented by hardware, software, or a combination of hardware and software.

[0088] The storage module 202 may include a high-speed random access memory (RAM), or may include a non-volatile memory such as one or more magnetic disk storages, a flash memory, or another non-volatile memory. In some embodiments, the storage module may further include a remote memory that is separate from the one or more processors 218, and the remote memory is, for example, a web disk accessed by an RF circuit 222, the peripheral port 214, and a communications network (not shown in FIG. 2). The communications network may be the Internet, an intranet, a local area network (LANs), a wide area network (WLANs), a storage area network (SANs), or a combination of the foregoing networks, or the like. Access of another component of the computing device 200 to the storage module 202, for example, access of the CPU 218 and the peripheral interface 220 to the storage module 202 may be controlled by using the storage controller 216.

[0089] The peripheral interface 220 couples a peripheral input and output of the computing device 200 to the CPU 218 and the storage module 202 of the device. The one or more processors 218 process data and accomplish various functions of the device 200 by running various software and/or executing various instructions stored in the storage module 202.

[0090] In some embodiments, the peripheral interface 220, the one or more processors 218, and the storage controller 216 may be integrated into one chip, for example, a chip. In some other embodiments, the peripheral interface 220, the one or more processors 218, and the storage controller 216 may be implemented by using different chips.

[0091] The RF circuit 222 receives and sends electromagnetic waves. The RF circuit 222 performs electrical/magnetic signal conversion, and communicates with the communications network or another communications device by using the electromagnetic waves. The RF circuit 222 may include a circuit system well known to a person skilled in the art, to perform the foregoing functions. For example, the circuit system includes, but is not limited to, an antenna system, an RF transceiver, one or more amplifiers, one tuner, one or more oscillators, one digital signal processor, one encoding and decoding chip set, one subscriber identity module card (SIM card), and a memory. The RF circuit 222 may communicate with a communications network such as the Internet, an intranet, and/or a wireless network, for example, a mobile phone network, a wireless local area network, and/or a metropolitan area network (MAN), or communicate with another

device connected to the foregoing networks. The communication may use various communication standards, protocols, and technologies, for example, including, but not limited to, the Hypertext Transfer Protocol (HTTP), the Global System for Mobile Communications (GSM), Enhanced Data rates for GSM Evolution (EDGE), a Wideband Code Division Multiple Access (W-CDMA) technology, a Code Division Multiple Access (CDMA) technology, a Time Division Multiple Access (TDMA) technology, Bluetooth, a Wireless Fidelity (Wi-Fi) technology (for example, IEEE 802.21a, IEEE 802.21b, IEEE 802.21g, and/or IEEE 802.21n), Voice over Internet Protocol (VoIP), a worldwide interoperability for microwave access (Wi-MAX), the Simple Mail Transfer Protocol, instant messaging (IM), and/or a short message service (SMS), or other communications protocols, including other suitable communications protocols that have not been developed on the date of this application.

[0092] In some embodiments, the computing device 200 further includes an audio circuit, an audio output device, and an audio input device (not shown), to provide an audio interface between the computing device 200 and a user. The audio circuit receives audio data from the peripheral interface 220, converts the audio data into an electrical signal, and transmits the electrical signal to the audio output device, for example, a loudspeaker. The audio output device converts the electrical signal into a sound wave that can be heard by the user. The audio circuit is further configured to receive an electrical signal that is converted from the sound wave by the audio input device, converts the electrical signal into audio data, and transmits the audio data to the peripheral interface 220 for processing. The audio data may be transmitted by the peripheral interface 220 to the storage module 202 and/or the RF circuit 222, or may be obtained from the storage module 202 and/or the RF circuit 222. In some embodiments, the audio circuit may further include an earphone jack (not shown in FIG. 2). The earphone jack provides an interface between the audio circuit and a peripheral movable audio input/output device. The movable audio input/output device may be an earphone having only an output function, or may be a device including both an input (a microphone) function and an output function.

[0093] In some embodiments, the computing device 200 further includes an I/O subsystem (not shown), to provide an interface between an input/output peripheral and the peripheral interface 220 of the computing device 200. For example, the input/output peripheral includes, but is not limited to, a display and another input/control device. The I/O subsystem includes a display controller and one or more input controllers for another output or control device. The one or more input controllers receive/send electrical signals from/to another input or control device. The another input/control device may include a physical button (for example, a pressing button, or a joystick button), a keyboard, a joystick, and the like.

[0094] In some embodiments, the storage module 202 includes an operating system 204, a

communication module (or an instruction set) 206, a graphics module (or an instruction set) 208, and one or more pieces of application software (or instruction sets) 208.

[0095] The operating system 204 (for example, Darwin, RTXC, Linux, Unix, OS X, Windows, or an embedded operating system such as VxWorks) includes various software components and/or drivers that are used for controlling and managing common system tasks (for example, memory management, control over a storage device, and power management) and that facilitate communication between various hardware and software components.

[0096] The communication module 206 is configured to communicate with another device through one or more peripheral ports 214, and further includes various software components used for processing data received by the RF circuit 222 and/or the peripheral port 214. The peripheral port 214 (for example, a universal serial bus (USB) or FireWire) is suitable to be coupled to another device indirectly by using a network (for example, the Internet or a wireless LAN) or directly.

[0097] The one or more pieces of application software 208 may include any application installed in the device 200. The application includes, but is not limited to, a browser, an address book, a contacts list, email, instant messaging, text processing, keyboard emulation, a widget (widget), a Java application, encryption, speech recognition, voice duplication, positioning (for example, a Global Positioning System GPS), and a music player.

[0098] FIG. 3 is a schematic structural diagram of a data transmission system 300 according to an embodiment of the present invention. As shown in FIG. 3, the data transmission system may include: an application server, a controller, a sending device, a receiving device, and a switching device. Connection of the system is performed by using a network 102. The controller is a logical control center of an SDN network. The controller is connected to the switching device through a southbound interface, provides a network instruction to the switching device, and manages a network topology between switching devices. The controller is connected to the application server through a northbound interface. The application server may control transmission of data from the sending device to the receiving device.

[0099] Computing logic or an application program runs on the sending device and the receiving device. The computing logic or the application program is managed by an application that runs on the application server. After a large bulk of data is processed by the computing logic or the application program of the sending device, a new bulk of data is formed, and the data needs to be sent, by means of scheduling and coordination by the application, to the receiving device for processing.

[0100] Physical ports of the sending device and the receiving device are connected to the SDN network managed by the controller, and the sending device and the receiving device are connected

to each other by using the network. As shown in FIG. 3, the sending device is connected to a port 11 of the switching device, and the receiving device is connected to a port 33 of the switching device.

[0101] The controller provides the northbound interface, and provides a function of customizing quality of service (Quality of Service, QoS) of a network path. The application that runs on the application server may access the northbound interface of the controller by using a management network.

[0102] In this embodiment of the present invention, the application server is configured to send a TCP transmission resource allocation request to the controller. The TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device.

[0103] The controller is configured to: determine a first transmission path and a second transmission path according to the TCP transmission resource allocation request, where the first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device; and send a TCP transmission resource allocation response message to the application server. The TCP transmission resource allocation response message includes bandwidth information of the first transmission path and a TCP round-trip transmission delay. The TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path.

[0104] The application server is further configured to: determine, according to a bandwidth of the first transmission path and the TCP round-trip transmission delay, an initial value of a transmit window for TCP data transmission between the sending device and the receiving device, where the initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately; and send a transmit window setting message to the sending device, where the transmit window setting message includes the initial value of the transmit window.

[0105] The sending device is configured to: set a size of the transmit window to the initial value of the transmit window according to the transmit window setting message, and perform TCP data transmission.

[0106] The initial value of the transmit window refers to an amount of data allowed to be sent within a first RTT time when the sending device performs TCP data transmission.

[0107] The controller is further configured to: obtain a transmission delay of the first transmission path and a transmission delay of the second transmission path; and determine the TCP round-trip transmission delay

[0116] Optionally, a size of the transmit window of the sending device may be expressed as:

Transmit window = Bandwidth of first transmission path × RTT.

[0117] Optionally, the controller is further configured to determine a packet loss rate of the first transmission path. In this case, the TCP transmission resource allocation response message further includes the packet loss rate of the first transmission path. The application server is further configured to determine the initial value of the transmit window according to the packet loss rate. The initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately and is negatively correlated with the packet loss rate.

[0118] Optionally, a size of the transmit window of the sending device may be expressed as:

Transmit window = Bandwidth of first transmission path × RTT × (1 – Packet loss rate).

[0119] Optionally, the application server is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path and the TCP round-trip transmission delay. The initial value of the receive window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0120] Optionally, a size of the receive window of the receiving device may be expressed as:

Rwnd = Bandwidth of first transmission path × RTT.

[0121] Optionally, the application server is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path, the TCP round-trip transmission delay, and the packet loss rate. The initial value of the receive window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately and is negatively correlated with the packet loss rate.

[0122] Optionally, a size of the receive window of the receiving device may be expressed as:

Rwnd = Bandwidth of first transmission path × RTT × (1 – Packet loss rate).

[0123] The application server is further configured to send a receive window setting message to the receiving device, and the receive window setting message includes the initial value of the receive window. The receiving device is configured to: set a size of the receive window to the initial value of the receive window according to an indication of the receive window setting message; and perform TCP data transmission.

[0124] Optionally, during subsequent TCP data transmission, the sending device may determine, according to that the transmit window equals Rwnd, a size of the transmit window for the TCP data transmission.

[0125] Optionally, the application server is further configured to determine an initial value of a

transmission path.

[0132] Optionally, the controller determines, within a value range indicated by the MTU value information, an optimal MTU value for the first transmission path according to an OAM feature of the first transmission path.

[0133] The sending device and the receiving device set MTU values of the devices to the optimal MTU value, so that it can be ensured that data is segmented according to an optimal length, and more effective TCP data transmission is implemented.

[0134] The controller is further configured to send an MTU setting message to the switching device on the first transmission path. The MTU setting message is used to instruct the switching device on the first transmission path to set an MTU value to the MTU value used by the first transmission path to transmit the data.

[0135] Optionally, the application server is further configured to: determine a retransmission timeout interval of the sending device according to the TCP round-trip transmission delay, where the retransmission timeout interval is positively correlated with the TCP round-trip transmission delay; and send a retransmission timeout interval setting message to the sending device, where the retransmission timeout interval setting message includes the retransmission timeout interval.

[0136] Optionally, the application server sets the retransmission timeout interval to a round-trip time RTT.

[0137] The retransmission timeout interval refers to a maximum wait time during which, after sending a data packet, the sending device waits for an acknowledgment of the data packet to be returned.

[0138] Optionally, the application server is further configured to: determine an acknowledgment wait time of the receiving device according to the TCP round-trip transmission delay, where the acknowledgment wait time is positively correlated with the TCP round-trip transmission delay; and send an acknowledgment wait time setting message to the receiving device, where the acknowledgment wait time setting message includes the acknowledgment wait time.

[0139] Optionally, the application server sets the acknowledgment wait time to a round-trip time RTT.

[0140] The acknowledgment wait time is a maximum wait time during which, after receiving a data packet, the receiving device postpones sending of an acknowledgment.

[0141] Optionally, the application server estimates an expected network bandwidth according to an amount of to-be-transmitted data, a schedule, and features of network interface cards in the sending device and the receiving device, and adds a requested path bandwidth for TCP data transmission to the TCP transmission resource allocation request.

resource identifier, a path resource for performing the TCP data transmission.

[0149] According to the technical solution provided in this embodiment, resources and parameters for TCP data transmission can be properly configured. When TCP data transmission is required, an application server sends a TCP transmission resource allocation request to a controller through a northbound interface provided by the controller. The controller configures a path for TCP data transmission according to the TCP transmission resource allocation request, and determines path information such as a bandwidth of the path, a TCP round-trip transmission delay, a packet loss rate of the path, and an optimal MTU value of the path. After the path information is returned to the application server, the application server can properly configure parameters for the TCP data transmission. According to these parameters, the application server can bypass a slow start process of TCP by setting an initial size of a transmit window for the TCP data transmission. In addition, an initial value of the transmit window is determined according to a bandwidth of a data transmission path and a TCP round-trip time. Therefore, transmission can be performed with a relatively high throughput, and a prior-art problem is avoided that halved oscillation of a sliding window caused by repeated network detection eventually affects a network throughput. An MTU value returned by the controller is used to ensure that data can be segmented according to an optimal length and transmitted on a network device, and more effective TCP data transmission is implemented.

[0150] FIG. 4 is a flowchart of an example of a data transmission method 400 according to an embodiment of the present invention, so as to implement more effective TCP data transmission. In a specific implementation process, the data transmission method 400 may be performed by a controller in an SDN data center. The method 400 is specifically applied to software-defined networking SDN, and a controller in the SDN network is a logical control center of the SDN network. The controller is connected to a switching device through a southbound interface, provides a network instruction to the switching device, and manages a network topology between switching devices. The controller is connected to an application server through a northbound interface. At least one application runs on the application server. When the application server determines that currently data needs to be transmitted from a sending device to a receiving device by using the TCP protocol, as shown in FIG. 4, the method specifically includes the following steps.

[0151] S402: The controller receives a TCP transmission resource allocation request from the application server, where the TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device.

[0152] Optionally, the address of the sending device and the address of the receiving device are Internet Protocol (Internet Protocol, IP) addresses or Media Access Control (Media Access Control, MAC) addresses.

[0153] Optionally, the controller provides the northbound interface, and provides a function of customizing quality of service (Quality of Service, QoS) of a network path. The application that runs on the application server may access the northbound interface of the controller by using a management network.

[0154] S404: The controller determines a first transmission path and a second transmission path according to the TCP transmission resource allocation request, where the first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device.

[0155] S406: The controller sends a TCP transmission resource allocation response message to the application server, where the TCP transmission resource allocation response message includes bandwidth information of the first transmission path and a TCP round-trip transmission delay, the TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path, and the bandwidth information of the first transmission path and the TCP round-trip transmission delay are used to determine an initial value of a transmit window for TCP data transmission between the sending device and the receiving device.

[0156] Before the sending, by the controller, a TCP transmission resource allocation response message to the application server, the method 400 further includes: obtaining, by the controller, a transmission delay of the first transmission path and a transmission delay of the second transmission path, and determining the TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path. The TCP round-trip transmission delay is positively correlated with a sum of the transmission delay of the first transmission path and the transmission delay of the second transmission path.

[0157] Optionally, the controller detects the transmission delay of the first transmission path and the transmission delay of the second transmission path according to operation, administration, and maintenance (Operation, Administration, and Maintenance, OAM) features of the first transmission path and the second transmission path, and determines the TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path.

[0158] Optionally, the TCP round-trip transmission delay is the sum of the transmission delay of the first transmission path and the transmission delay of the second transmission path.

[0159] Optionally, the controller further pre-estimates a TCP layer processing delay of the receiving device. The TCP round-trip transmission delay is a sum of the transmission delay of the

to a bandwidth of a data transmission path and a TCP round-trip time. Therefore, transmission can be performed with a relatively high throughput, and a prior-art problem is avoided that halved oscillation of a sliding window caused by repeated network detection eventually affects a network throughput. An MTU value returned by the controller is used to ensure that data can be segmented according to an optimal length and transmitted on a network device, and more effective TCP data transmission is implemented.

[0172] FIG. 5 is a flowchart of an example of a data transmission method 500 according to an embodiment of the present invention, so as to implement more effective TCP data transmission. The method 500 is specifically applied to software-defined networking SDN, and a controller in the SDN network is a logical control center of the SDN network. The controller is connected to a switching device through a southbound interface, provides a network instruction to the switching device, and manages a network topology between switching devices. The controller is connected to an application server through a northbound interface. In a specific implementation process, the data transmission method 500 may be performed by an application server in an SDN data center. More specifically, the method 500 may be performed by an application that runs on the application server. When the application determines that currently data needs to be transmitted from a sending device to a receiving device by using the TCP protocol, as shown in FIG. 5, the method specifically includes the following steps.

[0173] S502: The application server sends a TCP transmission resource allocation request to the controller, where the TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device.

[0174] S504: The application server receives a TCP transmission resource allocation response message from the controller, where the TCP transmission resource allocation response message includes a bandwidth of the first transmission path and a TCP round-trip transmission delay, the TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path, the first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device.

[0175] S506: The application server determines, according to the bandwidth of the first transmission path and the TCP round-trip transmission delay, an initial value of a transmit window for TCP data transmission between the sending device and the receiving device. The initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and

[0204] The retransmission timeout interval refers to a maximum wait time during which, after sending a data packet, the sending device waits for an acknowledgment of the data packet to be returned.

[0205] Optionally, the application server is further configured to: determine an acknowledgment wait time of the receiving device according to the TCP round-trip transmission delay, where the acknowledgment wait time is positively correlated with the TCP round-trip transmission delay; and send an acknowledgment wait time setting message to the receiving device, where the acknowledgment wait time setting message includes the acknowledgment wait time.

[0206] Optionally, the application server sets the acknowledgment wait time to a round-trip time RTT.

[0207] The acknowledgment wait time is a maximum wait time during which, after receiving a data packet, the receiving device postpones sending of an acknowledgment.

[0208] Specifically, the application server sends the TCP transmission resource allocation request to the controller through the northbound interface of the controller.

[0209] Optionally, the application server estimates an expected network bandwidth according to an amount of to-be-transmitted data, a schedule, and features of network interface cards in the sending device and the receiving device, and adds a requested path bandwidth for TCP data transmission to the TCP transmission resource allocation request.

[0210] Because a bandwidth for TCP data transmission when packet loss occurs on a path has been reserved, when the third repeated ACK is received at a TCP layer, it indicates that the path is in a congestion phase. The transmit window remains unchanged, and a lost packet is retransmitted.

[0211] Because a bandwidth for TCP data transmission when packet loss occurs on a path has been reserved, when timeout occurs, a packet whose ACK is not received is retransmitted, and the transmit window remains unchanged.

[0212] According to the technical solution provided in this embodiment, an application server can properly configure parameters for TCP data transmission. When TCP data transmission is required, the application server sends a TCP transmission resource allocation request to a controller through a northbound interface of the controller, and requests a path resource for the TCP data transmission. After the controller configures a path according to the TCP transmission resource allocation request, the application server receives a TCP transmission resource allocation response message sent by the controller. The application server determines the parameters for the TCP data transmission according to the TCP transmission resource allocation response message. A slow start process of TCP is bypassed by setting an initial size of a transmit window for the TCP data transmission. In addition, an initial value of the transmit window is determined according to a

bandwidth of a data transmission path and a TCP round-trip time. Therefore, transmission can be performed with a relatively high throughput, and a prior-art problem is avoided that halved oscillation of a sliding window caused by repeated network detection eventually affects a network throughput. An MTU value returned by the controller is used to ensure that data can be segmented according to an optimal length and transmitted on a network device, and more effective TCP data transmission is implemented.

[0213] FIG. 6 is a schematic diagram of a logical structure of a data transmission apparatus 600 according to an embodiment of the present invention. The apparatus 600 is applied to software-defined networking SDN, is connected to a switching device through a southbound interface, and is connected to an application server through a northbound interface. The application server is configured to control data to be sent from a sending device to a receiving device. As shown in FIG. 6, the data transmission apparatus 600 may include: a receiving unit 602, a determining unit 604, and a sending unit 606.

[0214] The receiving unit 602 is configured to receive a TCP transmission resource allocation request from the application server, and the TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device.

[0215] The determining unit 604 is configured to determine a first transmission path and a second transmission path according to the TCP transmission resource allocation request. The first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device.

[0216] The sending unit 606 is configured to send a TCP transmission resource allocation response message to the application server. The TCP transmission resource allocation response message includes bandwidth information of the first transmission path and a TCP round-trip transmission delay. The TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path. The bandwidth information of the first transmission path and the TCP round-trip transmission delay are used to determine an initial value of a transmit window for TCP data transmission between the sending device and the receiving device.

[0217] The determining unit 604 is further configured to: obtain a transmission delay of the first transmission path and a transmission delay of the second transmission path; and determine the TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path. The TCP round-trip transmission delay is positively correlated with

request to the controller, and the TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device.

[0237] The receiving unit 704 is configured to receive a TCP transmission resource allocation response message from the controller. The TCP transmission resource allocation response message includes a bandwidth of the first transmission path and a TCP round-trip transmission delay. The TCP round-trip transmission delay indicates a pre-estimated time difference between a time T1 at which the sending device sends each data packet through the first transmission path and a time T2 at which the sending device receives a TCP acknowledgment of each data packet through the second transmission path. The first transmission path is used by the sending device to transmit the data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device.

[0238] The determining unit 706 is configured to determine, according to the bandwidth of the first transmission path and the TCP round-trip transmission delay, an initial value of a transmit window for TCP data transmission between the sending device and the receiving device. The initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0239] Optionally, the TCP transmission resource allocation response message further carries a packet loss rate of the first transmission path. The determining unit 706 is further configured to determine the initial value of the transmit window according to the packet loss rate. The initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately and is negatively correlated with the packet loss rate.

[0240] Optionally, the determining unit 706 is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path and the TCP round-trip transmission delay. The initial value of the receive window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately.

[0241] Optionally, the determining unit 706 is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path, the TCP round-trip transmission delay, and the packet loss rate. The initial value of the receive window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately and is negatively correlated with the packet loss rate.

[0242] Specifically, the sending unit 702 is further configured to send a transmit window setting message to the sending device, and the transmit window setting message includes the initial value

retransmission timeout interval is positively correlated with the TCP round-trip transmission delay. In this case, the sending unit 702 is further configured to send a retransmission timeout interval setting message to the sending device, and the retransmission timeout interval setting message includes the retransmission timeout interval.

[0250] Optionally, the determining unit 706 is further configured to determine an acknowledgment wait time of the receiving device according to the TCP round-trip transmission delay, and the acknowledgment wait time is positively correlated with the TCP round-trip transmission delay. In this case, the sending unit is further configured to send an acknowledgment wait time setting message to the receiving device, and the acknowledgment wait time setting message includes the acknowledgment wait time.

[0251] The sending unit 702 sends the TCP transmission resource allocation request to the controller through the northbound interface of the controller.

[0252] Optionally, the determining unit 706 first determines a round-trip time RTT between the sending device and the receiving device according to the TCP round-trip transmission delay. The RTT is positively correlated with the TCP round-trip transmission delay.

[0253] Optionally, the determining unit 706 determines that the TCP round-trip transmission delay is the round-trip time RTT.

[0254] Optionally, the determining unit 706 further pre-estimates TCP layer processing delays of the sending device and the receiving device. The round-trip time RTT is a sum of the TCP round-trip transmission delay and the TCP layer processing delays of the sending device and the receiving device.

[0255] Optionally, the determining unit 706 further pre-estimates a TCP layer processing delay of the receiving device. The round-trip time RTT is a sum of the TCP round-trip transmission delay and the TCP layer processing delay of the receiving device.

[0256] Optionally, a size of the transmit window of the sending device may be expressed as:

Transmit window = Bandwidth of first transmission path × RTT.

[0257] Optionally, a size of the receive window of the receiving device may be expressed as:

Rwnd = Bandwidth of first transmission path × RTT.

[0258] Optionally, a size of the transmit window of the sending device may be expressed as:

Transmit window = Bandwidth of first transmission path × RTT × (1 – Packet loss rate).

[0259] Optionally, a size of the receive window of the receiving device may be expressed as:

Rwnd = Bandwidth of first transmission path × RTT × (1 – Packet loss rate).

[0260] Optionally, the determining unit 706 sets the retransmission timeout interval to a round-trip time RTT.

[0276] Optionally, the controller selects a set of available paths between the sending device and the receiving device according to a network topology of the switching device, and determines remaining bandwidths of ports of switching devices on the available paths. A bandwidth that has been allocated is subtracted from physical bandwidths of a port to obtain a remaining bandwidth of the port. A smallest value of remaining bandwidths of ports on a path is used as a remaining bandwidth of the path.

[0277] Optionally, the TCP transmission resource allocation request further includes a bandwidth required for transmitting the data. The determining, by the controller, a first transmission path according to the TCP transmission resource allocation request includes: selecting, according to a network topology of the switching device and from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data and are the fewest as the first transmission path.

[0278] Optionally, the determining, by the controller, a first transmission path according to the TCP transmission resource allocation request includes: selecting, according to a network topology of the switching device and from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data and whose hop count is the smallest as the first transmission path.

[0279] Optionally, if all remaining bandwidths of the set of available paths are less than a bandwidth requested by the application server, a path whose bandwidth is the largest is selected as the first transmission path.

[0280] The controller determines a transmission delay of the first transmission path and a transmission delay of the second transmission path, and determines a TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path. The TCP round-trip transmission delay is positively correlated with a sum of the transmission delay of the first transmission path and the transmission delay of the second transmission path.

[0281] Optionally, the controller detects the transmission delay of the first transmission path and the transmission delay of the second transmission path according to operation, administration, and maintenance (Operation, Administration, and Maintenance, OAM) features of the first transmission path and the second transmission path, and determines the TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path. The TCP round-trip transmission delay is positively correlated with the transmission delay of the first transmission path and the transmission delay of the second transmission path separately.

to a bandwidth of the first transmission path and the TCP round-trip transmission delay. The initial value of the transmit window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately. In this case, the sending a parameter setting message includes: sending an initial value setting message of the transmit window to the sending device.

[0290] Optionally, the controller first determines a round-trip time RTT between the sending device and the receiving device according to the TCP round-trip transmission delay. The RTT is positively correlated with the TCP round-trip transmission delay.

[0291] Optionally, it is determined that the TCP round-trip transmission delay is the round-trip time RTT.

[0292] Optionally, a size of the transmit window of the sending device may be expressed as:

Transmit window = Bandwidth of first transmission path × RTT.

[0293] Optionally, the determining, by the controller according to the first transmission path and/or the second transmission path, values of parameters for TCP data transmission includes: determining, by the controller, an initial value of a receive window of the receiving device according to a bandwidth of the first transmission path and the TCP round-trip transmission delay. The initial value of the receive window is positively correlated with the bandwidth of the first transmission path and the TCP round-trip transmission delay separately. In this case, the sending a parameter setting message includes: sending an initial value setting message of the receive window to the receiving device.

[0294] Optionally, a size of the receive window of the receiving device may be expressed as:

Rwnd = Bandwidth of first transmission path × RTT.

[0295] Optionally, the method 800 further includes: determining, by the controller, a packet loss rate of the first transmission path. The packet loss rate is used to indicate a packet loss status when the first transmission path is used for data transmission.

[0296] Optionally, the controller collects statistics about the packet loss rate on the first transmission path according to an experience library, adds a reserved packet loss rate, and determines information about the packet loss rate of the first transmission path.

[0297] Optionally, the controller enables an OAM feature of the first transmission path, and determines the packet loss rate of the first transmission path.

[0298] Optionally, the determining, according to the first transmission path and/or the second transmission path, values of parameters for TCP data transmission includes: determining an initial

[0320] Optionally, the TCP transmission resource allocation request further includes a bandwidth required for transmitting the data. The determining unit 904 being configured to determine a first transmission path according to a network topology of the switching device and the TCP transmission resource allocation request includes: selecting, by the determining unit 904 according to the network topology of the switching device and from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data and are the fewest as the first transmission path.

[0321] Optionally, the determining unit 904 being configured to determine a first transmission path according to a network topology of the switching device and the TCP transmission resource allocation request includes: selecting, by the determining unit 904 according to the network topology of the switching device and from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data and whose hop count is the smallest as the first transmission path.

[0322] Optionally, if all remaining bandwidths of the set of available paths are less than a bandwidth requested by the application server, the determining unit 904 selects a path whose bandwidth is the largest as the first transmission path.

[0323] The determining unit 904 determines a transmission delay of the first transmission path and a transmission delay of the second transmission path, and determines the TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path. The TCP round-trip transmission delay is positively correlated with a sum of the transmission delay of the first transmission path and the transmission delay of the second transmission path.

[0324] Optionally, the determining unit 904 detects the transmission delay of the first transmission path and the transmission delay of the second transmission path according to operation, administration, and maintenance (Operation, Administration, and Maintenance, OAM) features of the first transmission path and the second transmission path, and determines the TCP round-trip transmission delay according to the transmission delay of the first transmission path and the transmission delay of the second transmission path. The TCP round-trip transmission delay is positively correlated with the transmission delay of the first transmission path and the transmission delay of the second transmission path separately.

[0325] Optionally, the TCP round-trip transmission delay is the sum of the transmission delay of the first transmission path and the transmission delay of the second transmission path.

[0326] Optionally, the determining unit 904 further pre-estimates TCP layer processing delays of the sending device and the receiving device. The TCP round-trip transmission delay is a sum of

CLAIMS

1. A data transmission method, applied to software-defined networking SDN, wherein the method comprises:

receiving (S402), by a controller, a TCP transmission resource allocation request from a application server, wherein the TCP transmission resource allocation request carries an address of a sending device and an address of a receiving device;

determining (S404), by the controller, a first transmission path and a second transmission path according to the TCP transmission resource allocation request, wherein the first transmission path is used by the sending device to transmit data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device; and

sending (S406), by the controller, a TCP transmission resource allocation response message to the application server, wherein the TCP transmission resource allocation response message comprises bandwidth information of the first transmission path and a TCP round-trip transmission delay, and the bandwidth information of the first transmission path and the TCP round-trip transmission delay are used to determine an initial value of a transmit window for TCP data transmission between the sending device and the receiving device.

2. The method according to claim 1, before the sending, by the controller, a TCP transmission resource allocation response message to the application server, further comprising: determining, by the controller, a packet loss rate of the first transmission path; wherein

the TCP transmission resource allocation response message further comprises the packet loss rate of the first transmission path.

3. The method according to claim 1 or 2, wherein the TCP transmission resource allocation request further comprises a bandwidth required for transmitting the data; and

the determining, by the controller, a first transmission path according to the TCP transmission resource allocation request comprises: selecting, according to a network topology of the switching device and from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data as the first transmission path.

4. A data transmission method, applied to software-defined networking SDN, wherein the method comprises:

sending (5402), by a application server, a TCP transmission resource allocation request to a controller, wherein the TCP transmission resource allocation request carries an address of a sending device and an address of a receiving device;

receiving (S504), by the application server, a TCP transmission resource allocation response

message from the controller, wherein the TCP transmission resource allocation response message comprises a bandwidth of a first transmission path and a TCP round-trip transmission delay, the first transmission path is used by the sending device to transmit data to the receiving device; and

determining (S506), by the application server according to the bandwidth of the first transmission path and the TCP round-trip transmission delay, an initial value of a transmit window for TCP data transmission between the sending device and the receiving device.

5. The method according to claim 4, wherein the TCP transmission resource allocation response message further carries a packet loss rate of the first transmission path; and

the method further comprises: determining, by the application server, the initial value of the transmit window according to the packet loss rate.

6. The method according to claim 4 or 5, further comprising: determining, by the application server, an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path and the TCP round-trip transmission delay.

7. The method according to claim 5, further comprising: determining, by the application server, an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path, the TCP round-trip transmission delay, and the packet loss rate.

8. The method according to any one of claims 4 to 7, further comprising: sending, by the application server, a transmit window setting message to the sending device, wherein the transmit window setting message comprises the initial value of the transmit window.

9. The method according to claim 6 or 7, further comprising: sending, by the application server, a receive window setting message to the receiving device, wherein the receive window setting message comprises the initial value of the receive window.

10. A data transmission apparatus, applied to software-defined networking SDN, wherein the apparatus comprises:

a receiving unit (602), configured to receive a TCP transmission resource allocation request from a application server, wherein the TCP transmission resource allocation request carries an address of a sending device and an address of a receiving device;

a determining unit (604), configured to determine a first transmission path and a second transmission path according to the TCP transmission resource allocation request, wherein the first transmission path is used by the sending device to transmit data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device; and

a sending unit (606), configured to send a TCP transmission resource allocation response message to the application server, wherein the TCP transmission resource allocation response

message comprises bandwidth information of the first transmission path and a TCP round-trip transmission delay, and the bandwidth information of the first transmission path and the TCP round-trip transmission delay are used to determine an initial value of a transmit window for TCP data transmission between the sending device and the receiving device.

11. The apparatus according to claim 10, wherein the determining unit is further configured to determine a packet loss rate of the first transmission path; and

the TCP transmission resource allocation response message further comprises the packet loss rate of the first transmission path.

12. The apparatus according to claim 10 or 11, wherein the TCP transmission resource allocation request further comprises a bandwidth required for transmitting the data; and

the determining unit is configured to select, according to a network topology of the switching device and from paths between the sending device and the receiving device, a path whose remaining bandwidth resources meet a requirement for transmitting the data as the first transmission path.

13. A data transmission apparatus, applied to software-defined networking SDN, wherein the apparatus comprises:

a sending unit (702), configured to send a TCP transmission resource allocation request to a controller, wherein the TCP transmission resource allocation request carries an address of a sending device and an address of a receiving device;

a receiving unit (704), configured to receive a TCP transmission resource allocation response message from the controller, wherein the TCP transmission resource allocation response message comprises a bandwidth of a first transmission path and a TCP round-trip transmission delay, the first transmission path is used by the sending device to transmit the data to the receiving device; and

a determining unit (706), configured to determine, according to the bandwidth of the first transmission path and the TCP round-trip transmission delay, an initial value of a transmit window for TCP data transmission between the sending device and the receiving device.

14. The apparatus according to claim 13, wherein the TCP transmission resource allocation response message further carries a packet loss rate of the first transmission path; and

the determining unit is further configured to determine the initial value of the transmit window according to the packet loss rate.

15. The apparatus according to claim 13 or 14, wherein the determining unit is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth of the first transmission path and the TCP round-trip transmission delay.

16. The apparatus according to claim 14, wherein the determining unit is further configured to determine an initial value of a receive window of the receiving device according to the bandwidth

of the first transmission path, the TCP round-trip transmission delay, and the packet loss rate.

17. The apparatus according to any one of claims 13 to 16, wherein the sending unit is further configured to send a transmit window setting message to the sending device, wherein the transmit window setting message comprises the initial value of the transmit window.

18. The apparatus according to claim 15 or 16, wherein the sending unit is further configured to send a receive window setting message to the receiving device, wherein the receive window setting message comprises the initial value of the receive window.

19. A data transmission system (300), applied to software-defined networking SDN, and comprising an application server (110), a controller (108), a sending device and a receiving device;

the application server is configured to send a TCP transmission resource allocation request to the controller, wherein the TCP transmission resource allocation request carries an address of the sending device and an address of the receiving device;

the controller is configured to: determine a first transmission path and a second transmission path according to the TCP transmission resource allocation request, wherein the first transmission path is used by the sending device to transmit data to the receiving device, and the second transmission path is used by the receiving device to transmit a TCP acknowledgment to the sending device; and send a TCP transmission resource allocation response message to the application server, wherein the TCP transmission resource allocation response message comprises bandwidth information of the first transmission path and a TCP round-trip transmission delay;

the application server is further configured to: determine, according to a bandwidth of the first transmission path and the TCP round-trip transmission delay, an initial value of a transmit window for TCP data transmission between the sending device and the receiving device; and send a transmit window setting message to the sending device, wherein the transmit window setting message comprises the initial value of the transmit window; and

the sending device is configured to: set a size of the transmit window to the initial value of the transmit window according to the transmit window setting message; and perform TCP data transmission.

20. The system according to claim19, wherein the controller is further configured to determine a packet loss rate of the first transmission path; and

the TCP transmission resource allocation response message further comprises the packet loss rate of the first transmission path;

wherein the application server is further configured to determine the initial value of the transmit window according to the packet loss rate.