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Leung et al.

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(54) **SYSTEM AND METHOD TO ADAPT TO NETWORK CONGESTION**

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H04L 12/26 (2006.01)
H04L 12/56 (2006.01)
H04L 12/54 (2006.01)

(52) **U.S. Cl.**
USPC **370/229**; 370/412; 370/428

(58) **Field of Classification Search**
USPC 370/229, 235, 235.1, 236, 237, 412, 370/428, 429
See application file for complete search history.

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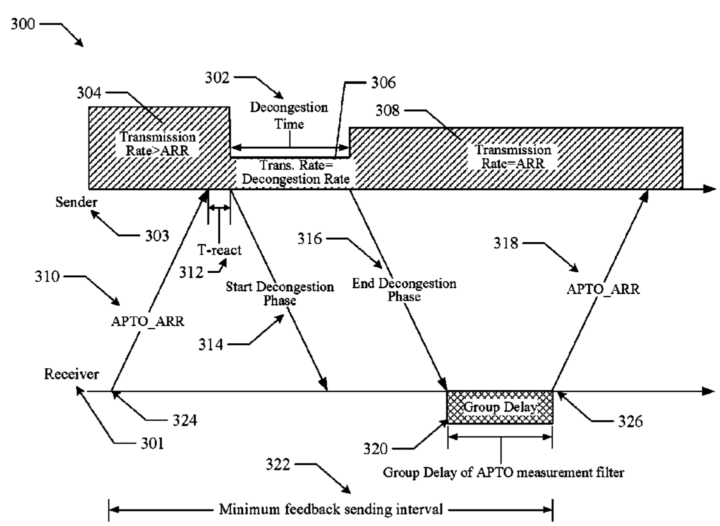
Primary Examiner — Warner Wong
(74) *Attorney, Agent, or Firm* — Todd E. Marlette

(57) **ABSTRACT**

In a particular embodiment, a method is disclosed that includes receiving a feedback message at a transmitter, the feedback message including an indication of a magnitude of congestion and a sustainable rate of data transmission at a receiver. The method also includes determining a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion when the magnitude of congestion satisfies a threshold value. The method further includes sending data at the decongestion rate from the transmitter to the receiver for the decongestion time. The method also includes adjusting a data transmission rate at the transmitter to the sustainable rate of data transmission after the decongestion time is ended.

29 Claims, 10 Drawing Sheets



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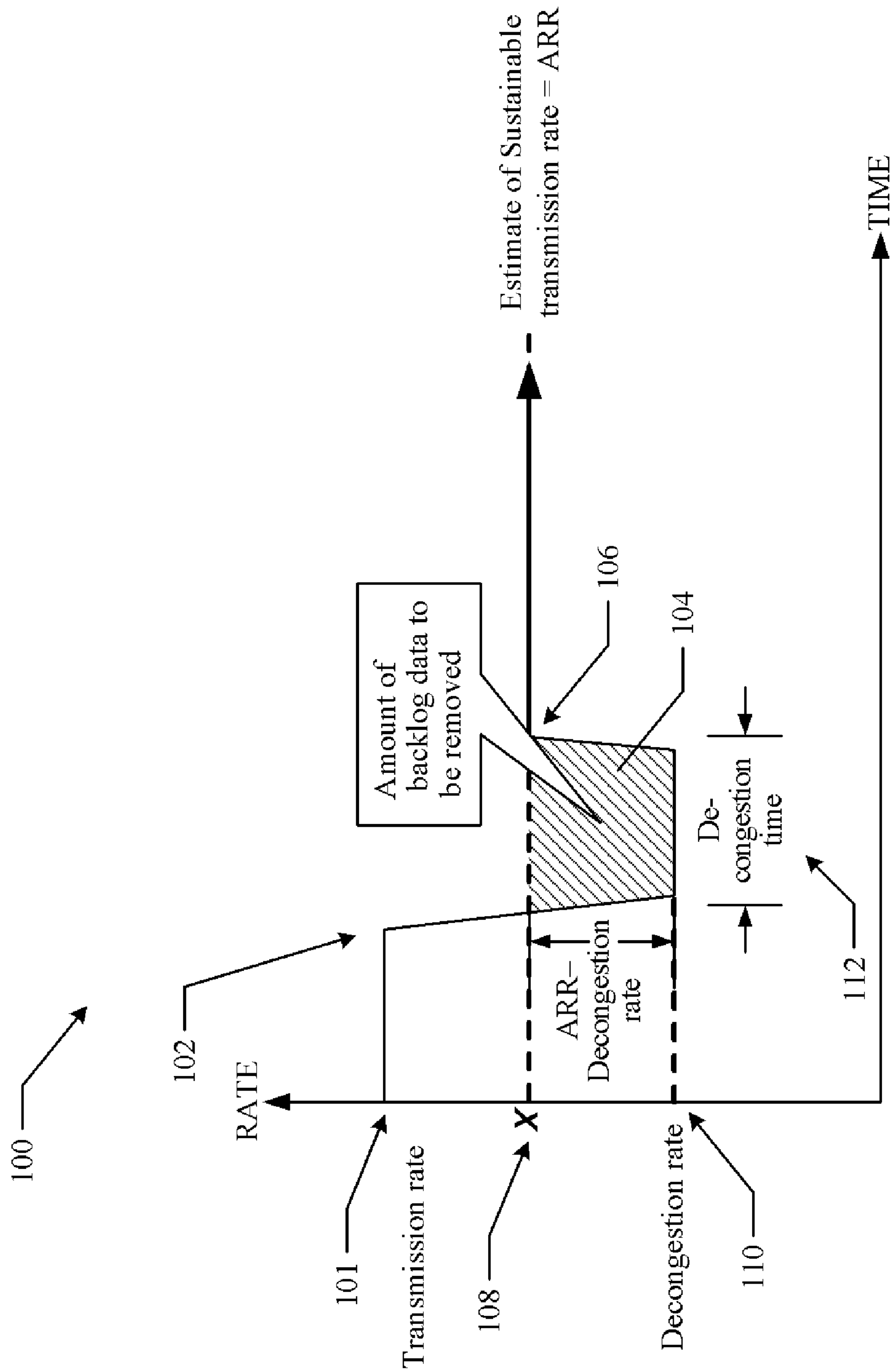
100
RATE
TIME
Transmission rate
101
102
X
108
Decongestion rate
110
ARR–
Decongestion
rate
104
106
Amount of
backlog data to
be removed
De-
congestion
time
112
Estimate of Sustainable
transmission rate = ARR

FIG. 1

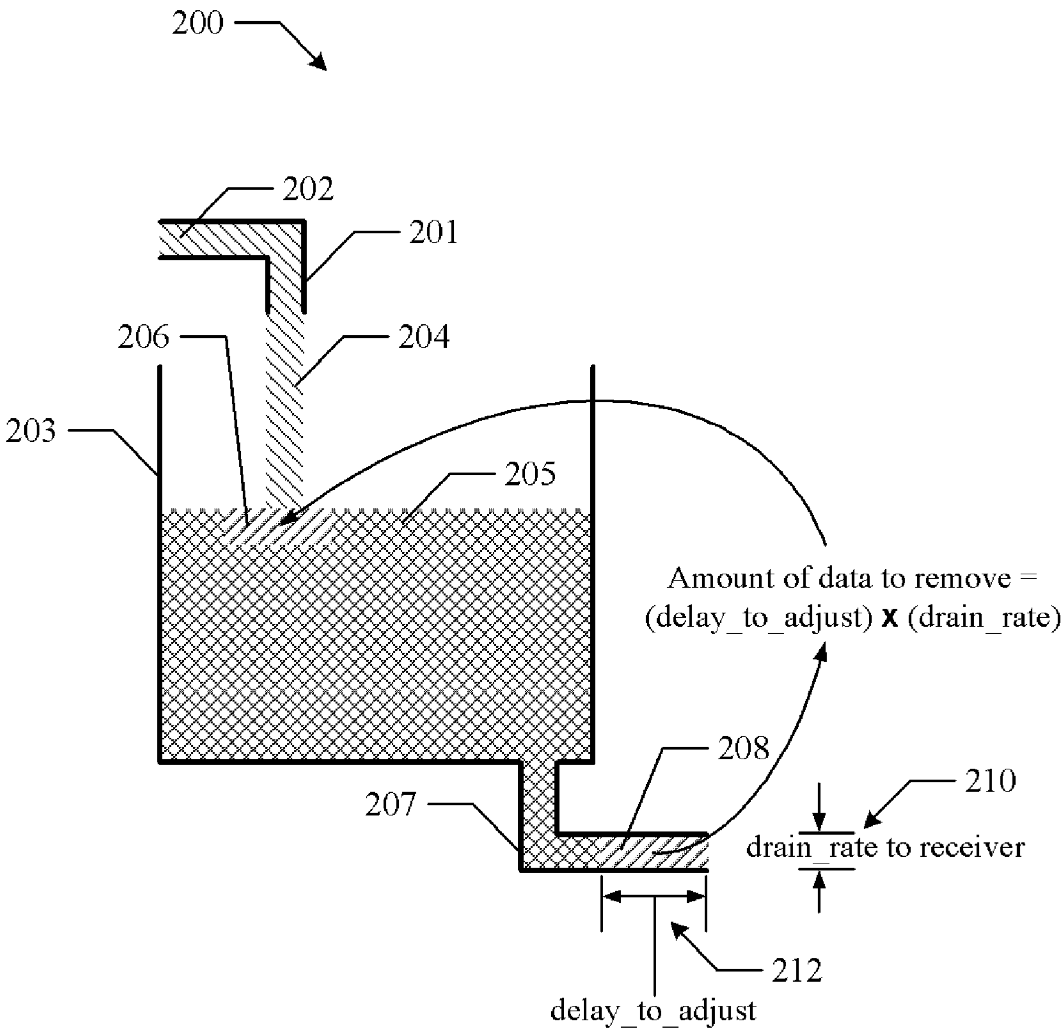
200
202
201
206
204
203
205
Amount of data to remove =
(delay_to_adjust) x (drain_rate)
208
210
207
drain_rate to receiver
212
delay_to_adjust

FIG. 2

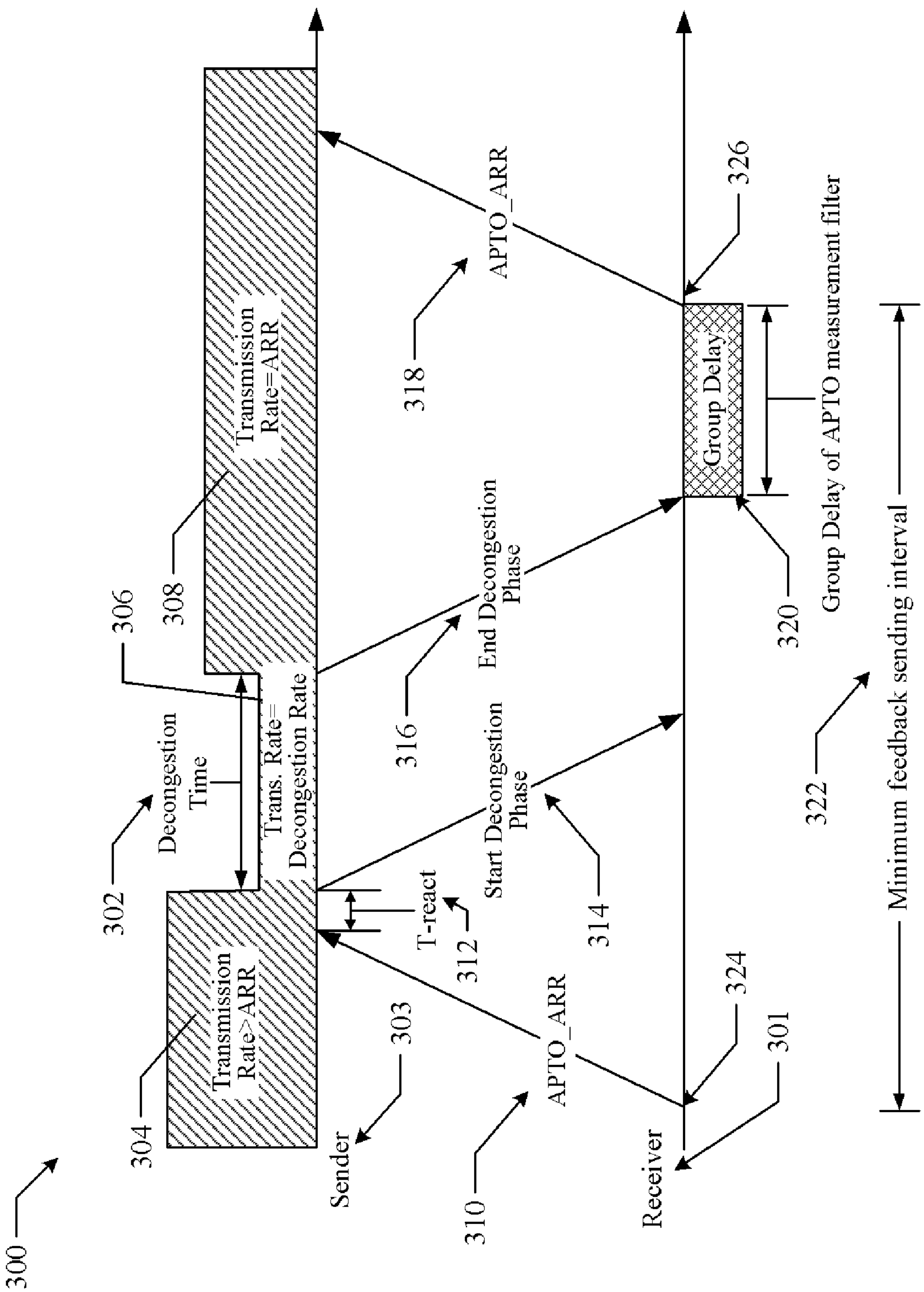
300
Sender
303
304
Transmission Rate>ARR
302
Decongestion Time
306
Trans. Rate= Decongestion Rate
308
Transmission Rate=ARR
310
APTO_ARR
312
T-react
314
Start Decongestion Phase
316
End Decongestion Phase
318
APTO_ARR
Receiver
301
324
326
Group Delay
320
Group Delay of APTO measurement filter
322
Minimum feedback sending interval

FIG. 3

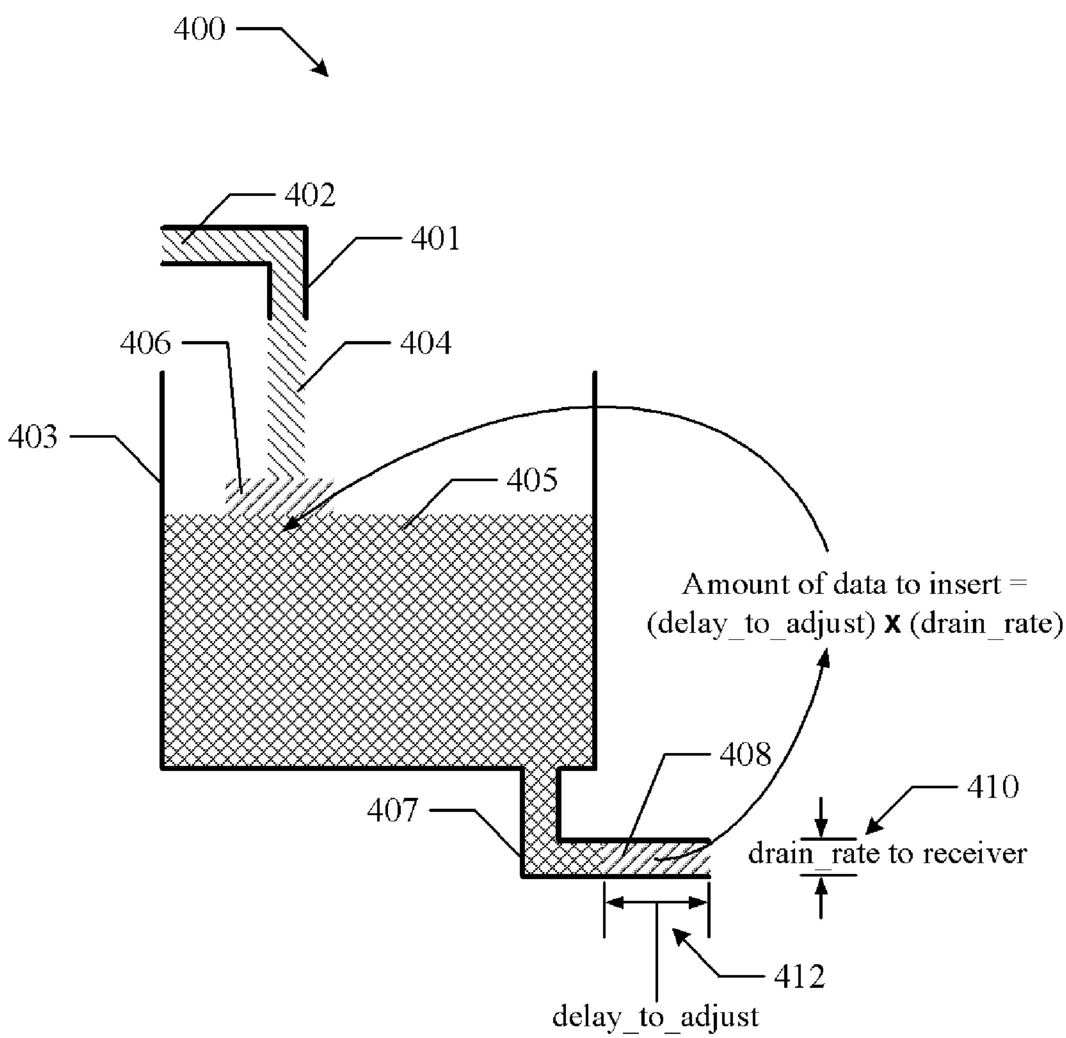
400
402
401
406
404
403
405
Amount of data to insert =
(delay_to_adjust) x (drain_rate)
408
410
407
drain_rate to receiver
412
delay_to_adjust

FIG. 4

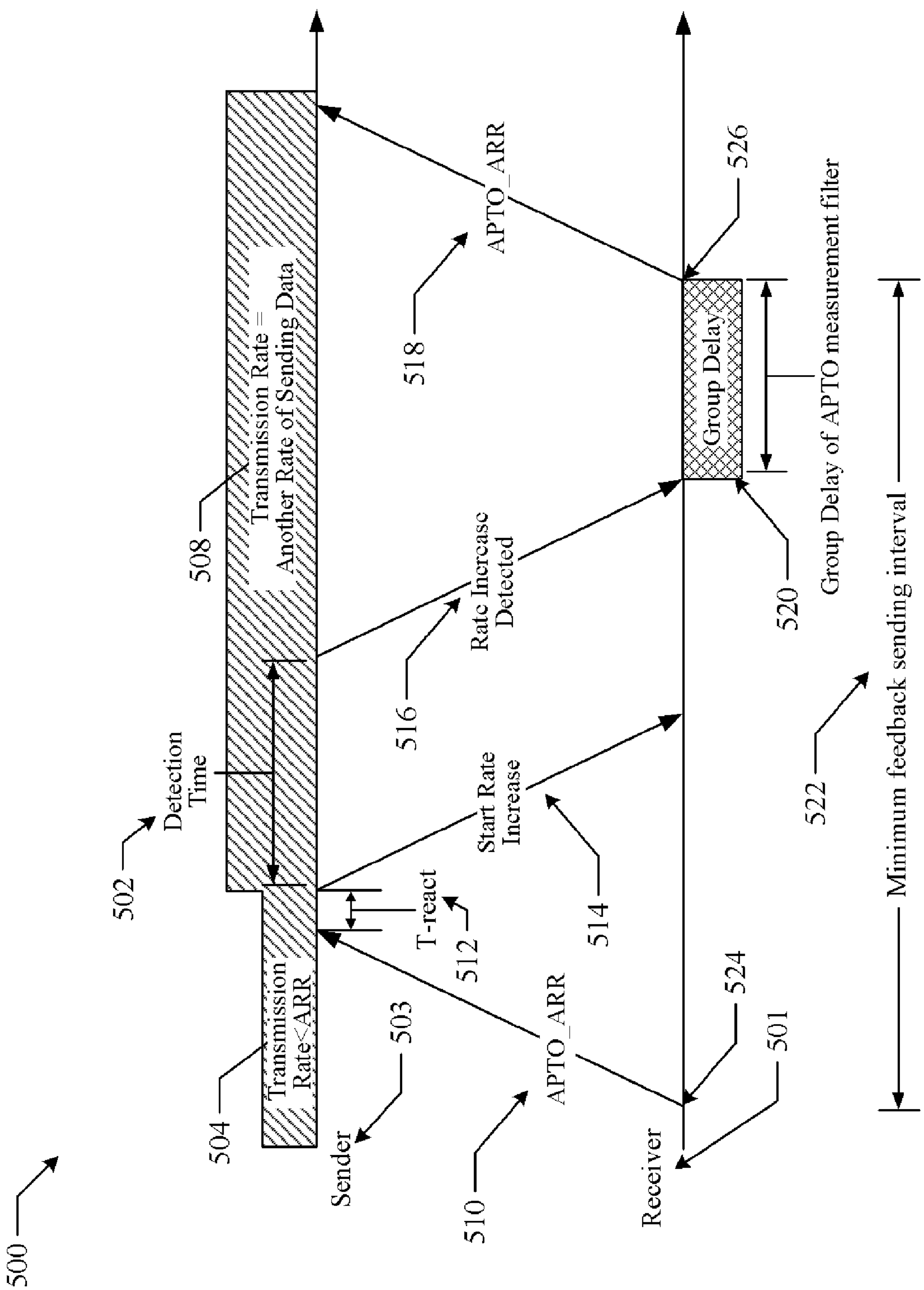
500
502
Detection Time
503
Sender
504
Transmission Rate<ARR
508
Transmission Rate = Another Rate of Sending Data
510
APTO_ARR
512
T-react
514
Start Rate Increase
516
Rate Increase Detected
518
APTO_ARR
520
Group Delay
Group Delay of APTO measurement filter
522
Minimum feedback sending interval
524
526
501
Receiver

FIG. 5

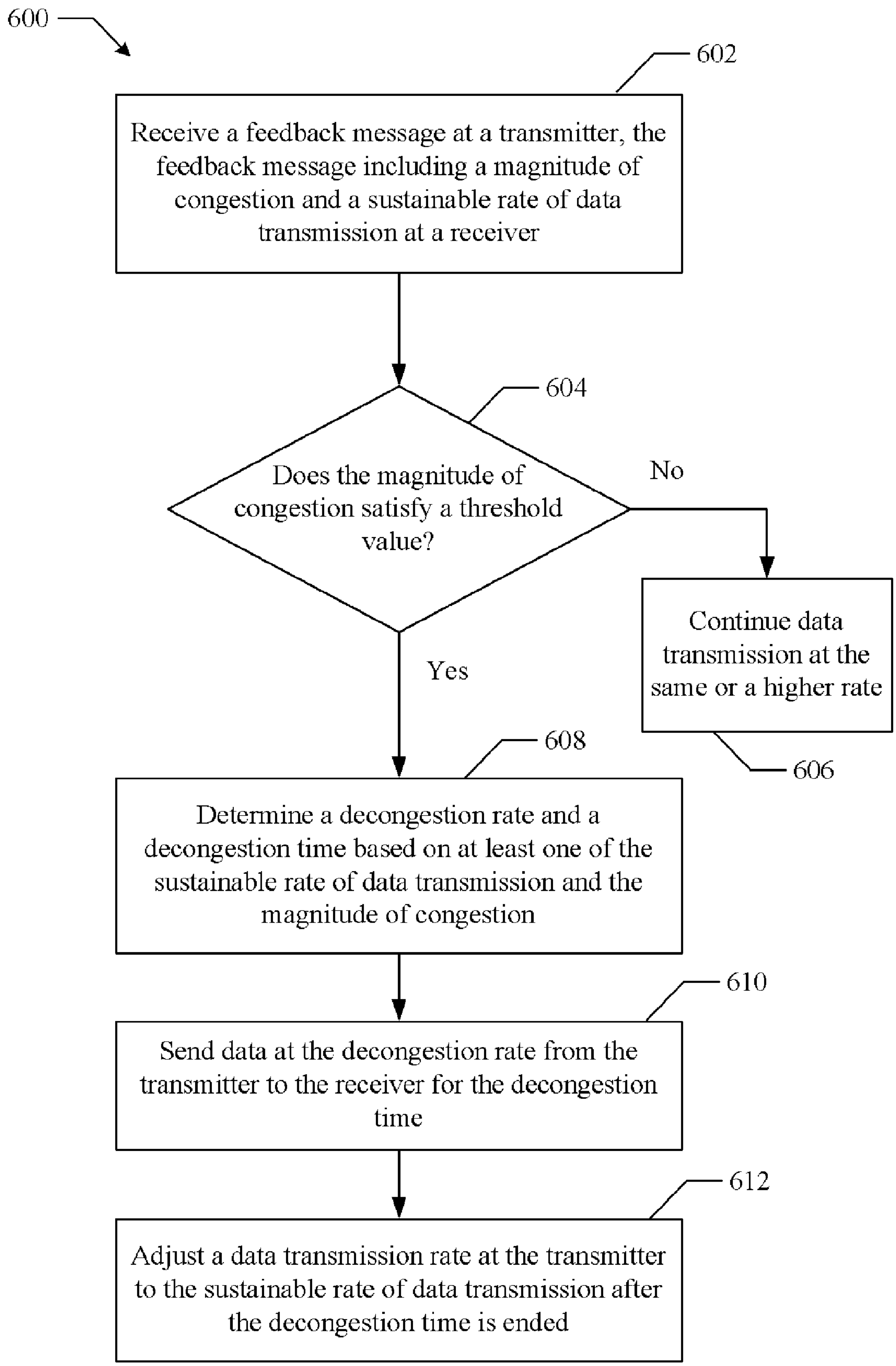
600
602
Receive a feedback message at a transmitter, the feedback message including a magnitude of congestion and a sustainable rate of data transmission at a receiver
604
Does the magnitude of congestion satisfy a threshold value?
No
Continue data transmission at the same or a higher rate
606
Yes
608
Determine a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion
610
Send data at the decongestion rate from the transmitter to the receiver for the decongestion time
612
Adjust a data transmission rate at the transmitter to the sustainable rate of data transmission after the decongestion time is ended

FIG. 6

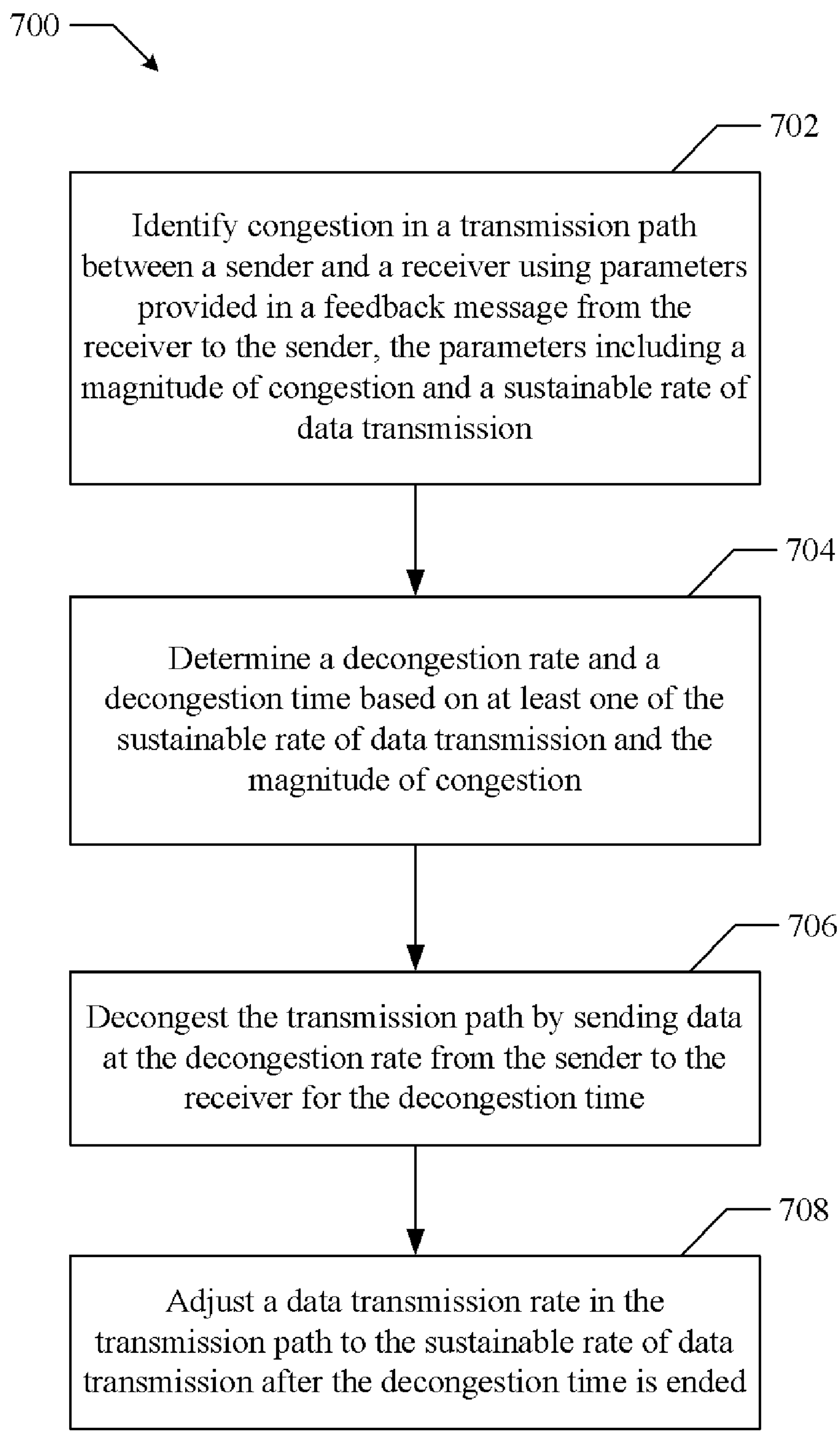
700
702
Identify congestion in a transmission path between a sender and a receiver using parameters provided in a feedback message from the receiver to the sender, the parameters including a magnitude of congestion and a sustainable rate of data transmission
704
Determine a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion
706
Decongest the transmission path by sending data at the decongestion rate from the sender to the receiver for the decongestion time
708
Adjust a data transmission rate in the transmission path to the sustainable rate of data transmission after the decongestion time is ended

FIG. 7

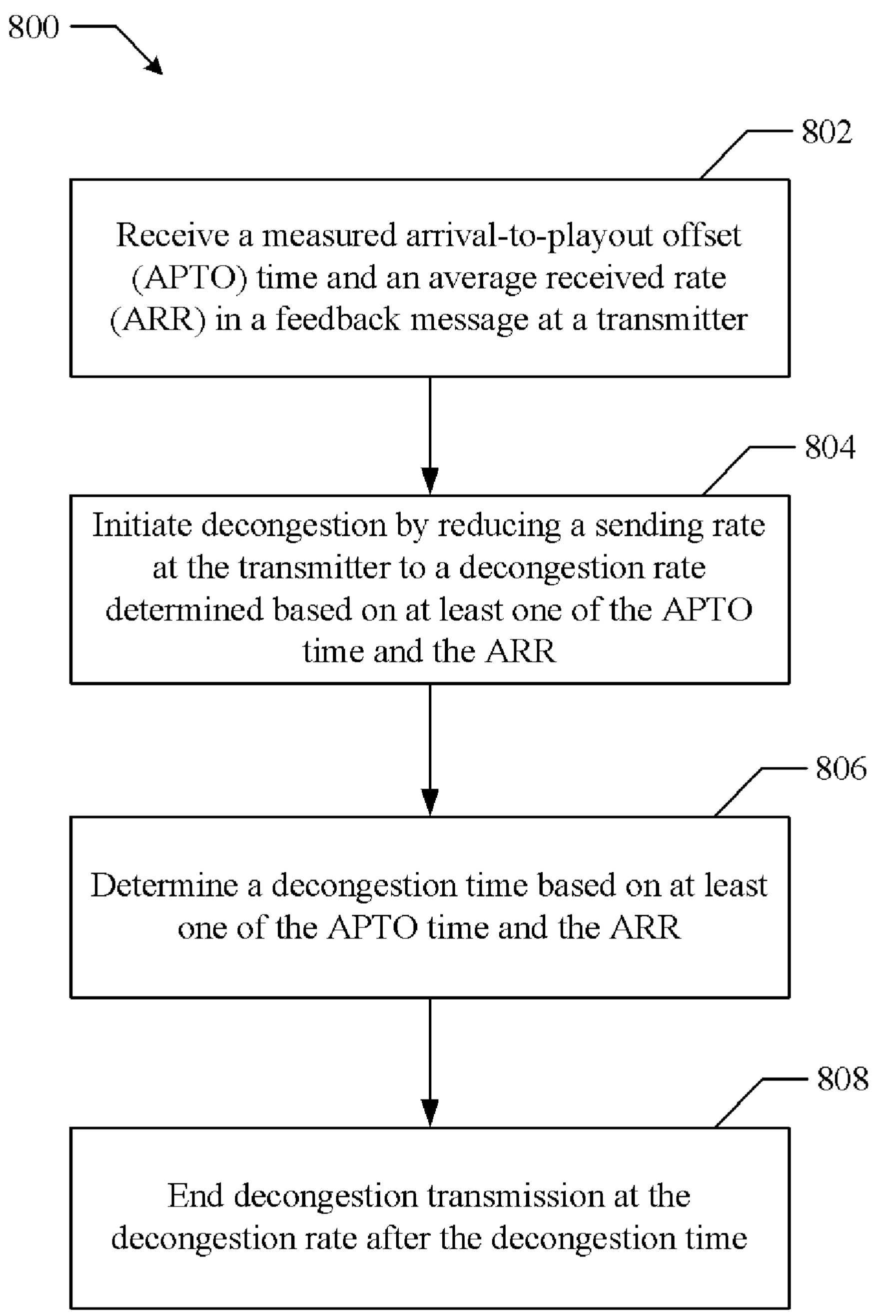
800
802
Receive a measured arrival-to-playout offset (APTO) time and an average received rate (ARR) in a feedback message at a transmitter
804
Initiate decongestion by reducing a sending rate at the transmitter to a decongestion rate determined based on at least one of the APTO time and the ARR
806
Determine a decongestion time based on at least one of the APTO time and the ARR
808
End decongestion transmission at the decongestion rate after the decongestion time

FIG. 8

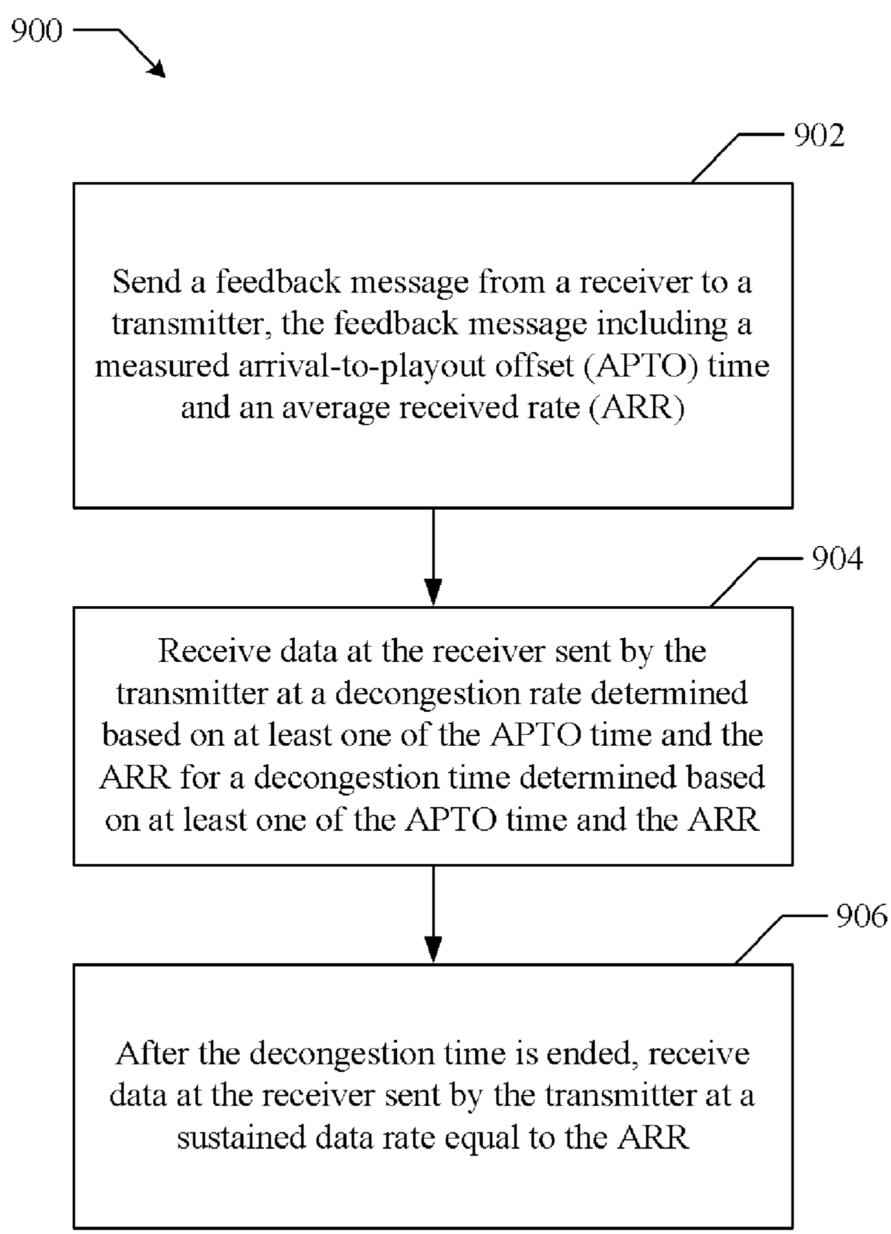
900
902
Send a feedback message from a receiver to a transmitter, the feedback message including a measured arrival-to-playout offset (APTO) time and an average received rate (ARR)
904
Receive data at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO time and the ARR for a decongestion time determined based on at least one of the APTO time and the ARR
906
After the decongestion time is ended, receive data at the receiver sent by the transmitter at a sustained data rate equal to the ARR

FIG. 9

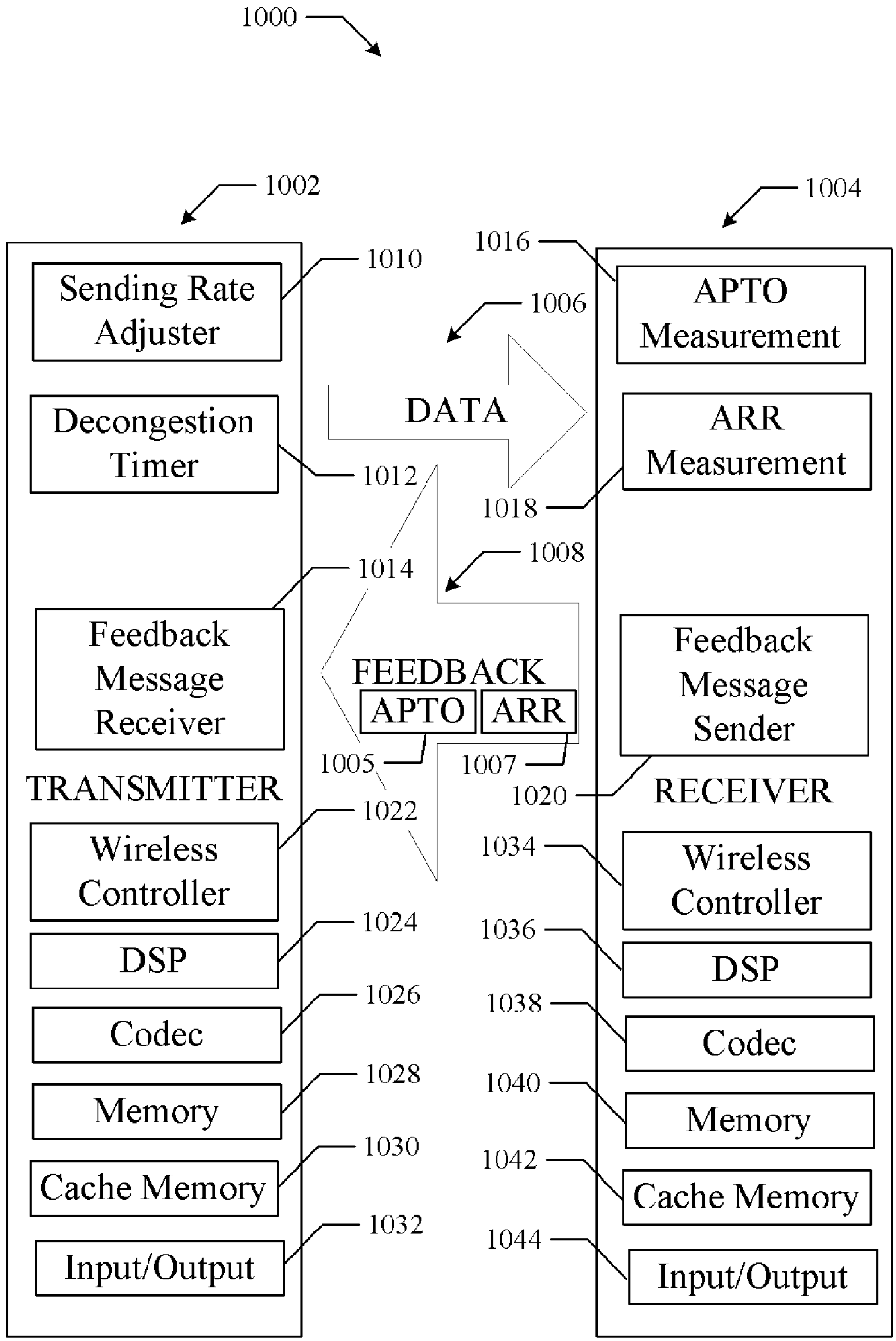
1000
1002
1004
Sending Rate Adjuster
1010
1016
APTO Measurement
1006
DATA
Decongestion Timer
1012
ARR Measurement
1018
1008
1014
Feedback Message Receiver
FEEDBACK
APTO
ARR
Feedback Message Sender
1005
1007
TRANSMITTER
1020
RECEIVER
Wireless Controller
1022
1034
Wireless Controller
DSP
1024
1036
DSP
Codec
1026
1038
Codec
Memory
1028
1040
Memory
Cache Memory
1030
1042
Cache Memory
Input/Output
1032
1044
Input/Output

FIG. 10

SYSTEM AND METHOD TO ADAPT TO NETWORK CONGESTION

CLAIM OF PRIORITY UNDER 35 U.S.C. §119

The present Application for Patent claims priority to Provisional Application No. 61/020,368 entitled "METHOD AND APPARATUS FOR ADAPTING RATE-TRAJECTORY TO NETWORK CONGESTION" filed Jan. 10, 2008 and assigned to the assignee hereof and hereby expressly incorporated by reference herein.

RELATED APPLICATION

The present application relates to U.S. application Ser. No. 11/315,399, filed on Dec. 21, 2005, entitled "Methods and Systems for Adaptive Encoding of Real-Time Information in Packet-Switched Wireless Communication Devices", and U.S. application Ser. No. 11/972,594, filed on Jan. 10, 2008, entitled "Content- and Link-Dependent Coding Adaptation for Multimedia Telephony", and assigned to the assignee hereof, and expressly incorporated by reference herein.

FIELD OF THE DISCLOSURE

The present disclosure is generally directed to systems and methods to adapt to network congestion.

BACKGROUND

When a sending terminal in a network detects congestion or easing of congestion in the network, the sending terminal may determine how to adapt the transmission rate of data sent from the sending terminal. The problem of determining what transmission rate to choose based on feedback received from a receiver in the network may be challenging. Proper selection of the adaptation rate may improve the convergence of the adaptation control loop and may improve the quality of service. However, frequently oscillating rate adjustments towards convergence may degrade the service experience, particularly for real-time services. Another challenge of rate adaptation is to determine how quickly to increase the transmission rate when congestion has eased. Increasing the rate too aggressively may quickly introduce further congestion if the sender is unaware of the channel condition, which may lead to a poor service experience because of the increase of the transmission rate followed by the sudden need to decrease the transmission rate due to the further congestion. Increasing the rate too conservatively may prevent the sender from making full use of the decongested channel as the decongested channel develops additional capacity.

Conventional approaches typically adapt to feedback by changing the send rate to a fixed value until another feedback message is received and the congestion status information is updated, involving multiple feedback messages. Such conventional approaches do not attempt to adapt to network congestion based on a single feedback message. During congestion, achieving a multi-phase adaptation of decongestion followed by transmission at the maximum sustainable rate requires multiple feedback messages from the receiver describing the status of the channel. During easing of congestion, the sender conventionally uses very conservative increases in rate along with waiting for feedback to ensure that the sender does not re-introduce congestion. Also, when congestion has eased, conventional approaches typically blindly probe the channel with additional data to get an estimate of the maximum sustainable rate of the channel. The blind probing may introduce additional delay if the blind probing re-introduces congestion and the channel is unable to transport the additionally inserted data in a timely manner.

SUMMARY

In a particular embodiment, a method is disclosed that includes receiving a feedback message at a transmitter, the feedback message including an indication of a magnitude of congestion and a sustainable rate of data transmission at a receiver. The method also includes determining a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion when the magnitude of congestion satisfies a threshold value. The method further includes sending data at the decongestion rate from the transmitter to the receiver for the decongestion time. The method also includes adjusting a data transmission rate at the transmitter to the sustainable rate of data transmission after the decongestion time is ended. In a particular embodiment, the sustainable rate of data transmission may be an estimated or predicted maximum sustainable rate.

In another embodiment, a method is disclosed that includes identifying congestion in a transmission path between a sender and a receiver using parameters provided in a feedback message from the receiver to the sender, the parameters including a magnitude of congestion and a sustainable rate of data transmission. The method also includes determining a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion. The method further includes decongesting the transmission path by sending data at the decongestion rate from the sender to the receiver for the decongestion time. The method also includes adjusting a data transmission rate in the transmission path to the sustainable rate of data transmission after the decongestion time is ended.

In another embodiment, a method is disclosed that includes receiving a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR) in a feedback message at a transmitter. The method also includes increasing a sending rate at the transmitter to an increased sending rate determined based on at least one of the APTO value and the ARR. The method further includes continuing transmission at the increased sending rate after a detection time, wherein the detection time is determined based on at least one of the APTO value and the ARR.

In another embodiment, a computer-readable medium including computer executable instructions is disclosed. The computer executable instructions are operable to cause a computer to send a feedback message from a receiver to a transmitter, the feedback message including a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR). The computer executable instructions are operable to cause a computer to receive data at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO value and the ARR for a decongestion time determined based on at least one of the APTO value and the ARR. The computer executable instructions are operable to cause a computer to receive data at the receiver sent by the transmitter at a sustained data rate of the ARR after the decongestion time is ended. In alternative embodiments, the decongestion time may be set as a fixed constant T_decongest that is determined based on how quickly the service/user experience requires that decongestion be achieved. For example, the service requirement may be that decongestion be achieved within about 1000 milliseconds to avoid too much disruption to a video stream. In other

alternative embodiments, the decongestion time may be set adaptively based on other measurements or criteria aside from the APTO value received.

In another embodiment, a method is disclosed that includes sending a feedback message from a receiver to a transmitter, the feedback message including a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR). The method also includes receiving data at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO value and the ARR for a decongestion time determined based on at least one of the APTO value and the ARR. The method further includes receiving data at the receiver sent by the transmitter at the maximum sustained data rate of the ARR after the decongestion time is ended.

In another embodiment, an apparatus is disclosed that includes means for sending a feedback message from a receiver to a transmitter. The feedback message includes a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR). The apparatus also includes means for receiving data at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO value and the ARR for a decongestion time determined based on at least one of the APTO value and the ARR. The apparatus further includes means for receiving data at the receiver sent by the transmitter at the maximum sustained data rate of the ARR after the decongestion time is ended.

In another embodiment, an apparatus is disclosed that includes a processor configured to generate a feedback message to send from a receiver to a transmitter. The feedback message includes a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR). Data is received at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO value and the ARR for a decongestion time determined based on at least one of the APTO value and the ARR. Data is received at the receiver sent by the transmitter at the maximum sustained data rate of the ARR after the decongestion time is ended.

In another embodiment, an apparatus is disclosed that includes a transmitter configured to transmit data, to receive a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR) in a feedback message, to initiate decongestion by reducing a sending rate at the transmitter to a decongestion rate determined based on at least one of the APTO value and the ARR, and to end decongestion transmission at the decongestion rate after a decongestion time determined based on at least one of the APTO value and the ARR.

In another embodiment, an apparatus is disclosed that includes means for initiating decongestion by reducing a sending rate at a transmitter to a decongestion rate determined based on at least one of a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR) that are received in a feedback message. The apparatus also includes means for ending decongestion transmission at the decongestion rate after a decongestion time determined based on at least one of the APTO value and the ARR.

One particular advantage provided by the disclosed embodiments is that channel decongestion and then transmission at the maximum sustainable rate under congestion conditions may be achieved.

Another advantage provided by the disclosed embodiments is that a ramp-up of rate above the current transmission rate that does not reintroduce congestion under conditions of congestion easing may be achieved.

Other aspects, advantages, and features of the present disclosure will become apparent after review of the entire application, including the following sections: Brief Description of the Drawings, Detailed Description, and the Claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of a particular illustrative embodiment of modifying a transmission rate to adapt to network congestion;

FIG. **2** is a diagram of a particular illustrative embodiment of a fluid model of network congestion to determine an amount of congested data to remove from a network;

FIG. **3** is a timing diagram of a particular illustrative embodiment of adapting a transmission rate to network congestion to decongest the transmission path;

FIG. **4** is a diagram of a particular illustrative embodiment of using a fluid model of congestion to determine an amount of data to insert into a network;

FIG. **5** is a timing diagram of a particular illustrative embodiment of adapting a transmission rate to network congestion to ramp-up data transmission;

FIG. **6** is a flow diagram of a first illustrative embodiment of a method to adapt to network congestion;

FIG. **7** is a flow diagram of a second illustrative embodiment of a method to adapt to network congestion;

FIG. **8** is a flow diagram of a third illustrative embodiment of a method to adapt to network congestion;

FIG. **9** is a flow diagram of a fourth illustrative embodiment of a method to adapt to network congestion; and

FIG. **10** is a diagram of a particular illustrative embodiment of a system that is adaptable to network congestion.

DETAILED DESCRIPTION

Referring to FIG. **1**, a diagram of a particular illustrative embodiment of modifying a transmission rate to adapt to network congestion is depicted and generally designated **100**. The diagram **100** depicts a transmission rate of a transmitter as a function of time. Initially, the transmitter sends data at a first transmission rate **101**. A feedback message may be received at the transmitter, as indicated at **102**. The feedback message includes an indication of a magnitude of congestion of a transmission network and a sustainable rate of data transmission **108** at a receiver that receives data from the transmitter. A decongestion rate **110** and a decongestion time **112** may be determined based on at least one of the sustainable rate of data transmission **108** and the magnitude of congestion when the magnitude of congestion satisfies a threshold value. After determining the magnitude of congestion and the sustainable rate of data transmission **108**, data may be sent at the decongestion rate **110** from the transmitter to the receiver for the decongestion time **112**, as indicated at **104**. A data transmission rate at the transmitter may be adjusted to the sustainable rate of data transmission **108** after the decongestion time **112** is ended, as indicated at **106**. In a particular embodiment, the transmitter transmits the data to the receiver via a wireless network. In a particular embodiment, the sustainable rate of data transmission may be substantially the maximum sustainable rate of data transmission. As used herein, the term maximum sustainable rate of data transmission is an estimated or predicted maximum sustainable rate of data transmission.

Including the magnitude of congestion and the maximum sustainable rate of data transmission enables the sender or transmitter to determine rate-trajectories based on a single feedback message. Either the sender or the transmitter may estimate the amount of congested bits in the transmission path. Based on this estimate and the estimate of the maximum sustainable rate of data transmission provided in the single feedback message, the sender or transmitter may determine a set of rates that may achieve channel decongestion and then transmission at the maximum sustainable rate under congestion conditions.

In a particular embodiment, the magnitude of congestion may be measured by an arrival-to-playout time offset (APTO) value and the maximum sustainable rate of data transmission **108** may be measured by an average received rate (ARR) of data received at the receiver. In a particular embodiment, congestion in an uplink, a downlink, and a core network may be reflected in a standardized APTO_ARR feedback message from the receiver to the sender or transmitter. The APTO_ARR is defined in the 3GPP2 C.P0055-A standard, and has been proposed for the 3GPP TS 26.114 standard. Information in the standardized APTO_ARR feedback message may indicate congestion at the receiver where data packets are not arriving at the receiver in time for properly scheduled playout. Information in the standardized APTO_ARR feedback message may also provide an estimate for guidance on what rate may be sustainable for the end-to-end transmission path. The standardized APTO_ARR feedback message may indicate the average received rate (ARR) at the receiver and also the receiver's request to advance or delay arrival times of data packets (APTO) based on playout needs. The delay may serve as an outer loop variable of a real-time packet (RTP) service.

In a particular embodiment, sending the data from the transmitter to the receiver at the decongestion rate **110** for the decongestion time **112** may remove an amount of congested data, the amount of congested data removed being substantially equal to a product of the decongestion time **112** and a difference between the ARR **108** and the decongestion rate **110**, as shown in FIG. **1**. In a particular embodiment, the amount of congested data removed may also be equal to a product of the APTO value and the ARR **108**. In a particular embodiment, during congestion the sender or transmitter rate adapts down to enable the data packets to arrive at the receiver in time for playout, initially by removing the backlog caused by congestion and then by operating at the maximum sustainable rate of the system that does not introduce further congestion or another backlog. If the backlog is not removed initially, then just operating at the maximum sustainable rate may not correct the current congestion state and the data packets may still be delayed. In a particular embodiment, during easing of congestion the sender or transmitter rate adapts up to improve the quality of the data transmission while ensuring that data packets arrive at the receiver in time for proper playout, improving the quality of the data transmission. When the data packets are from a video encoder, the resulting video quality may be thereby improved, for example.

Referring to FIG. **2**, a diagram of a particular illustrative embodiment of a fluid model of network congestion to determine an amount of congested data to remove from a network is depicted and generally designated **200**. A spout **201** directs a data packet stream **202** into a bucket **203**. An amount of data **205** accumulates in the bucket **203** before being drained out of the bucket **203** through a drain **207**. When the inflow of the data through the spout **201** equals the outflow of the data through the drain **207**, the amount of data **205** in the bucket **203** remains constant. When the inflow of the data through the spout **201** is greater than the outflow of the data through the drain **207**, the amount of the data **205** accumulating in the bucket **203** increases, indicating a state of congestion in the data transmission path. When the inflow of the data through the spout **201** is less than the outflow of the data through the drain **207**, the amount of the data **205** accumulating in the bucket **203** decreases, which decongests the data transmission path.

Data packets from a video encoder may enter the data packet stream, as indicated at **202**. An amount of congested data to remove **208** may be equal to the product of a delay_to_adjust time **212** and a drain_rate **210** to the receiver. In a particular embodiment, the delay_to_adjust time **212** may be equal to the APTO value and the drain_rate **210** may be equal to the ARR **108** of FIG. **1**. The encoder rate of data transmission may be reduced to the decongestion rate **110** for the decongestion time **112** to remove an amount of data **206** from the bucket **203**, where the amount of data **206** removed from the bucket **203** may be equal to the amount of congested data to remove **208**. Once the backlog of the amount of data **206** has been removed, data packets **204** arriving after the decongestion time **112** may leave the bucket **203** at the proper playout time. In a particular embodiment, the ARR **108** may serve as an estimate of the drain_rate **210** of the bucket and the sender or transmitter may remove a number of octets of congested data from the bucket **203** equal to the product of the APTO value and the ARR **108**. As described above, when the inflow of the data through the spout **201** (the encoder rate of data transmission) is less than the outflow of the data through the drain **207** (the drain_rate **210**), the amount of the data **205** accumulating in the bucket **203** decreases, which decongests the data transmission path. The ARR **108** may also serve as an estimate of the maximum sustainable rate through the system and may be used to transmit at the maximum sustainable rate of the ARR **108** once congestion is removed. In a particular embodiment, the ARR **108** may be measured for media throughput, real-time packet (RTP) throughput, which allows a video encoder, for example, to use the ARR **108** for a rate control target rate.

Referring to FIG. **3**, a diagram of a particular illustrative embodiment of a method to adapt to network congestion by showing how fast to decongest a transmission path is depicted and generally designated **300**. In a particular embodiment, the diagram **300** illustrates timing associated with decongestion according to FIG. **1**. Initially, as indicated at **304**, a transmission rate may be greater than the ARR **108**. The receiver **301** may measure an unacceptable APTO value, as indicated at **324**, and send an APTO_ARR feedback message **310** to the sender or transmitter **303**. The APTO_ARR feedback message **310** may be received at the sender or transmitter **303**, which may take a time T_react to react to the APTO_ARR feedback message **310**, as indicated at **312**. The sender or transmitter **303** may react to the APTO_ARR feedback message **310** by reducing the transmission rate to the decongestion rate **110**, as indicated at **306**, for the decongestion time **112**, as indicated at **302**. The start of the decongestion phase propagates to the receiver **301**, as indicated at **314**, and the end of the decongestion phase propagates to the receiver **301**, as indicated at **316**. After the decongestion time **112** has ended, the transmission rate is increased to the ARR **108**, as indicated at **308**. A group delay of the APTO measurement filter is indicated at **320**. A minimum feedback sending interval is indicated at **322**. Finally, as indicated at **326**, the receiver **301** checks the APTO measurement to determine whether another APTO_ARR feedback message **318** needs to be sent to the sender or transmitter **303**.

In a particular embodiment, the channel may be decongested before the receiver **301** makes the next decision about the state of congestion. In a particular embodiment, the transmission path may be decongested as fast as possible to quickly ease congestion at the receiver **301**. However, very aggressive decongestion requires reducing the data transmission to a much lower decongestion rate **110**, which may unacceptably degrade video performance during the decongestion phase when the data packets contain encoded video data. In a particular embodiment, the decongestion rate **110** may be at least equal to a rate to achieve an acceptable frame quality and an acceptable frame rate. The rate to achieve an acceptable frame quality and an acceptable frame rate may be a rate that produces video frames that maintain an acceptable peak signal-to-noise ratio (PSNR), because otherwise the video frame may be skipped in accord with a variable frame rate (VFR). In another particular embodiment, the decongestion rate **110** may be at least equal to a rate to achieve a minimum frame quality and a minimum frame rate. The rate to achieve a minimum frame quality and a minimum frame rate may be a rate that produces video frames that maintain a minimum peak signal-to-noise ratio (PSNR), because otherwise the video frame may be skipped in accord with a variable frame rate (VFR).

In a particular embodiment, the decongestion time **112** may be proportional to the APTO value with a constant of proportionality F. The decongestion time **112** may also be proportional to the amount or magnitude of congestion. The decongestion rate **110** may be proportional to the ARR **108** with a constant of proportionality equal to a ratio of (F−1) to F. For video data, the decongestion rate **110** may be achieved by encoding each frame at a target rate of the ARR **108** and then skipping every Fth frame. For example, when F equals two, the decongestion time **112** may be twice the APTO value and the decongestion rate **110** may be half the ARR **108**. For video data, the video encoder may skip sending every other frame encoded at the target rate of the ARR **108** for a time period of twice the APTO value.

In alternative embodiments, the decongestion time may be set as a fixed constant T_decongest that is determined based on how quickly the service/user experience requires that decongestion be achieved. For example, the service requirement may be that decongestion be achieved within about 1000 milliseconds to avoid too much disruption to a video stream. The decongestion rate may then be equal to the product of the ARR with (1−APTO/T_decongest). In other alternative embodiments, the decongestion time may be set adaptively to T_decongest_adapt based on other measurements or criteria aside from the APTO value received. For example, the measurements or criteria may include quality of service considerations, total network usage, the number of users, the amount of usage per user, and the like. The decongestion rate may then be equal to the product of the ARR with (1−APTO/T_decongest_adapt).

Referring to FIG. **4**, a diagram of a particular illustrative embodiment of a method to adapt to network decongestion/easing of congestion using the fluid model of congestion is depicted and generally designated **400**. A spout **401** directs a data packet stream **402** into a bucket **403**. An amount of data **405** accumulates in the bucket **403** before being drained out of the bucket **403** through a drain **407**. When the inflow of the data through the spout **401** equals the outflow of the data through the drain **407**, the amount of data **405** in the bucket **403** remains constant. When the inflow of the data through the spout **401** is greater than the outflow of the data through the drain **407**, the amount of the data **405** accumulating in the bucket **403** increases, indicating a state of congestion in the data transmission path. When the inflow of the data through the spout **401** is less than the outflow of the data through the drain **407**, the amount of the data **405** accumulating in the bucket **403** decreases, indicating that there is room to insert additional data into the data packet stream **402** without increasing the congestion of the system.

Data packets from a video encoder may enter the data packet stream, as indicated at **402**. An amount of insertable data to insert **408** may be equal to the product of a delay_to_adjust time **412** and a drain_rate **410** to the receiver. As described above, when the inflow of the data through the spout **401** is less than the outflow of the data through the drain **407**, the amount of the data **405** accumulating in the bucket **403** decreases, indicating that there is room to insert additional data into the data packet stream **402** without causing additional congestion. In a particular embodiment, the delay_to_adjust time **412** may be equal to the absolute value of the APTO value and the drain_rate **410** may be greater than or at least equal to the ARR **108**. The encoder rate of data transmission may be increased to another rate of sending data long enough to insert an amount of data **406** into the bucket **403**, where the amount of data **406** inserted into the bucket **403** may be equal to the amount of insertable data to insert **408**. Once the amount of data **406** has been inserted, data packets **404** arriving after the insertion phase may leave the bucket **403** at the proper playout time. In a particular embodiment, the transmission rate of the transmitter may be increased to a rate higher than a current rate of data transmission when the magnitude of congestion is less than a threshold value. In a particular embodiment, the transmission rate of the transmitter may be increased to a rate higher than the ARR **108** when the APTO value is less than a threshold value.

In a particular embodiment, the APTO value indicates a difference in the arrival statistic of data packets at the receiver compared to when the data packets are scheduled for proper playout without jitter, for video data. The APTO value may be an indication of the amount of delay the receiver would like to adjust in the end-to-end transmission path between the video sender and receiver. If there is congestion, then the APTO value may be positive and backlog packets in the bucket may be drained by the APTO value to remove the delay, as shown in FIG. **2**. If there is an easing of congestion, then the APTO value may be negative and the encoder may increase the transmission rate to use the additional bandwidth, where an amount of delay may be introduced that is equal to the absolute value of the APTO value, as shown in FIG. **4**.

Referring to FIG. **5**, a diagram of a particular illustrative embodiment of a method to adapt to network congestion by showing how fast to ramp-up data transmission is depicted and generally designated **500**. Initially, as indicated at **504**, a transmission rate may be less than the ARR **108**. In another embodiment, the transmission rate may not be less than the ARR **108**. The receiver **501** may measure an APTO value that is less than a threshold value, as indicated at **524**, and send an APTO_ARR feedback message **510** to the sender or transmitter **503**. The APTO_ARR feedback message **510** may be received at the sender or transmitter **503**, which may take a time T_react to react to the APTO_ARR feedback message **510**, as indicated at **512**. The sender or transmitter **503** may react to the APTO_ARR feedback message **510** by increasing the transmission rate to another rate of sending data, as indicated at **508**, for at least a detection time, as indicated at **502**. The start of the rate increase propagates to the receiver **501**, as indicated at **514**, and the end of the detection time, when the rate increase is detected at the receiver **501**, propagates to the receiver **501**, as indicated at **516**. A group delay of the APTO measurement filter is indicated at **520**. A minimum feedback sending interval is indicated at **522**. Finally, as indicated at **526**, the receiver **501** checks the APTO measurement to determine whether another APTO_ARR feedback message **518** needs to be sent to the sender or transmitter **503**.

In a particular embodiment, for the sake of convenience, the detection time may be set to be equal to the decongestion time **112**. In a particular embodiment, the detection time may be equal to the decongestion time **112** and may also be proportional to the absolute value of the last received APTO value with a constant of proportionality F. In a particular embodiment, another rate of sending data may be determined to accomplish an addition of insertable data into the network that may be distributed over a time period that is proportional to the decongestion time **112** with a constant of proportionality R. In a particular embodiment, another rate of sending data may be equal to the product of the ARR **108** and the sum of one and the reciprocal of the product of R and F. In another particular embodiment, another rate of sending data may be equal to the product of the sender's current transmission rate and the sum of one and the reciprocal of the product of R and F. In other particular embodiments, the detection time may be a constant, or the detection time may be set adaptively. The detection time may therefore be determined based on at least one of the APTO value, the ARR, a constant value, or an adaptively set value

Referring to FIG. **6**, a flow diagram of a particular illustrative embodiment of a method to adapt to network congestion is depicted and generally designated **600**. The method **600** includes receiving a feedback message at a transmitter, the feedback message including a magnitude of congestion and a sustainable rate of data transmission at a receiver, as indicated at **602**. For example, the APTO_ARR feedback message **310** may be received at a transmitter, the APTO_ARR feedback message **310** including a magnitude of congestion, the APTO value, and the sustainable rate of data transmission, the ARR **108**, as depicted in FIG. **1** and FIG. **3**. The method **600** includes determining whether the magnitude of congestion satisfies a threshold value, as indicated at **604**. For example, the APTO value may be positive, indicating congestion, and may be larger than a predetermined amount, indicating too much congestion. If the magnitude of congestion does not satisfy a threshold value, then the method **600** includes continuing data transmission at the same or a higher rate, as indicated at **606**. For example, if the APTO is less than a threshold amount, then the transmission rate may be increased to another rate of sending data, as depicted in FIG. **5**.

If the magnitude of congestion does satisfy the threshold value, then the method **600** includes determining a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion, as indicated at **608**. For example, the decongestion time **112** of FIG. **1** may be proportional to the APTO value with a constant of proportionality F, and the decongestion rate **110** may be proportional to the ARR **108** with a constant of proportionality equal to a ratio of (F−1) to F. The method **600** includes sending data at the decongestion rate from the transmitter to the receiver for the decongestion time, as indicated at **610**. For example, data may be sent at the decongestion rate **110** from the transmitter to the receiver for the decongestion time **112**, as depicted in FIG. **1** and FIG. **3**. The method **600** also includes adjusting a data transmission rate at the transmitter to the sustainable rate of data transmission after the decongestion time is ended, as indicated at **612**. For example, the data transmission rate at the transmitter may be adjusted to the ARR **108** after the decongestion time **112** is ended, as depicted in FIG. **1** and FIG. **3**.

Referring to FIG. **7**, a flow diagram of another particular illustrative embodiment of a method to adapt to network congestion is depicted and generally designated **700**. The method **700** includes identifying congestion in a transmission path between a sender and a receiver using parameters provided in a feedback message from the receiver to the sender, the parameters including a magnitude of congestion and a sustainable rate of data transmission, as indicated at **702**. For example, the APTO_ARR feedback message **310** may be received at a transmitter, the APTO_ARR feedback message **310** including a magnitude of congestion, the APTO value, and the sustainable rate of data transmission, the ARR **108**, as depicted in FIG. **1** and FIG. **3**. The method **700** includes determining a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion, as indicated at **704**. For example, the decongestion time **112** may be proportional to the APTO value with a constant of proportionality F, and the decongestion rate **110** may be proportional to the ARR **108** with a constant of proportionality equal to a ratio of (F−1) to F. The method **700** includes decongesting the transmission path by sending data at the decongestion rate from the sender to the receiver for the decongestion time, as indicated at **706**. For example, data may be sent at the decongestion rate **110** from the transmitter to the receiver for the decongestion time **112**, as depicted in FIG. **1** and FIG. **3**. The method **700** includes adjusting a data transmission rate in the transmission path to the sustainable rate of data transmission after the decongestion time is ended, as indicated at **708**. For example, the data transmission rate at the transmitter may be adjusted to the ARR **108** after the decongestion time **112** is ended, as depicted in FIG. **1** and FIG. **3**.

In a particular embodiment, the magnitude of congestion is an arrival-to-playout time offset (APTO) value measured at the receiver. In a particular embodiment, the sustainable rate of data transmission **108** is an average received rate (ARR) of data transmission of data received at the receiver, as shown in FIG. **1**. In a particular embodiment, the sustainable rate of data transmission **108** is the maximum rate of data transmission that does not cause congestion of the transmission path. In a particular embodiment, decongesting the transmission path removes an amount of backlogged data, the amount of backlogged data being substantially equal to a product of the decongestion time **112** and a difference between the ARR **108** and the decongestion rate **110**, as shown in FIGS. **1-3**.

In a particular embodiment, the decongestion time **112** is proportional to the APTO value, with a constant of proportionality F, and the decongestion rate **110** is proportional to the ARR, with a constant of proportionality equal to a ratio of (F−1) to F. The method **700** may also include determining a quantity of insertable data that can be inserted into the transmission path before the transmission path starts to become congested, where insertion of the insertable data into the transmission path is distributed over a time period that is proportional to the decongestion time **112** with a constant of proportionality R. In a particular embodiment, another rate of sending data may be determined based on the ARR **108** and a product of R and F. In a particular embodiment, another rate of sending data may be equal to the product of the ARR **108** and the sum of one and the reciprocal of the product of R and F. In other particular embodiments, the period of inserting the insertable data may be a constant or may be set adaptively based on other parameters or criteria, such as quality of service considerations, total network usage, the number of users, the amount of usage per user, and the like.

Referring to FIG. **8**, a flow diagram of yet another particular illustrative embodiment of a method to adapt to network congestion is depicted and generally designated **800**. The method **800** includes receiving a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR) in a feedback message at a transmitter, as indicated at **802**. For example, the APTO_ARR feedback message **510** may be received at a transmitter, the APTO_ARR feedback message

510 including the APTO value and the ARR, as depicted in FIG. 5. The method 800 includes increasing a sending rate at the transmitter to an increased sending rate determined based on at least one of the APTO value and the ARR, as indicated at 804. For example, the sending rate at the transmitter may be increased to another rate 508, as shown in FIG. 5, and another rate 508 may be proportional to the ARR.

The method 800 includes determining a detection time based on at least one of the APTO value and the ARR, as indicated at 806. For example, the detection time 502 of FIG. 5 may be proportional to the absolute value of the APTO value with a constant of proportionality F. The method 800 includes continuing transmission at the increased sending rate after the detection time, as indicated at 808. For example, data may be sent at another rate 508 from the transmitter 503 to the receiver 501 after the detection time 502, as depicted in FIG. 5.

The method 800 may also include determining a quantity of insertable data that can be inserted into a transmission path before the transmission path starts to become congested, wherein insertion of the insertable data into the transmission path is distributed over a time period that is proportional to the detection time 502 of FIG. 5 with a constant of proportionality R. The method 800 may also include adding insertable data distributed over a data insertion time period that is proportional to the detection time 502 of FIG. 5 with a constant of proportionality R, where the detection time 502 is proportional to the absolute value of the APTO value with a constant of proportionality F, where the increased sending rate 508 is determined based on the ARR and a product of R and F. In a particular embodiment, the increased sending rate 508 of sending data may be equal to the product of the ARR and the sum of one and the reciprocal of the product of R and F. In another particular embodiment, the insertable data may be inserted over a fixed or constant detection time value.

Referring to FIG. 9, a flow diagram of still another particular illustrative embodiment of a method to adapt to network congestion is depicted and generally designated 900. The method 900 includes sending a feedback message from a receiver to a transmitter, the feedback message including a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR), as indicated at 902. For example, the APTO_ARR feedback message 310 may be sent to a transmitter, the APTO_ARR feedback message 310 including the APTO value and the ARR 108, as depicted in FIG. 1 and FIG. 3.

The method 900 includes receiving data at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO value and the ARR for a decongestion time determined based on at least one of the APTO value and the ARR, as indicated at 904. For example, data may be received at the receiver sent by the transmitter at the decongestion rate 110 for the decongestion time 112, as depicted in FIG. 1 and FIG. 3. The decongestion time 112 may be proportional to the APTO value with a constant of proportionality F, and the decongestion rate 110 may be proportional to the ARR 108 with a constant of proportionality equal to a ratio of (F−1) to F. The method 900 includes, after the decongestion time is ended, receiving data at the receiver sent by the transmitter at a sustained data rate equal to the ARR, as indicated at 906. For example, the data transmission rate at the transmitter may be adjusted to the ARR 108 after the decongestion time 112 is ended, as depicted in FIG. 1 and FIG. 3.

In a particular embodiment, the decongestion time 112 is proportional to the APTO value with a constant of proportionality F, and the decongestion rate 110 is proportional to the ARR 108 with a constant of proportionality equal to a ratio of (F−1) to F. The method 900 may also include receiving additional inserted data at the receiver, the additional inserted data received during an insertion time period. In a particular embodiment, the insertion time period may be proportional to the decongestion time 112 with a constant of proportionality R. In other particular embodiments, the insertion time period may be constant or may be set adaptively based on other measurements or criteria, such as quality of service considerations, total network usage, the number of users, the amount of usage per user, and the like.

Referring to FIG. 10, a diagram of a particular illustrative embodiment of a system that is adaptable to network congestion is depicted and generally designated 1000. The system 1000 includes a transmitter 1002 configured to transmit data 1006. The system 1000 also includes means for receiving the data 1006, such as a receiver 1004 configured to receive the data 1006. The means for receiving may include a digital data receiver, a digital data packet receiver, a digital video data receiver, a digital video data packet receiver, a wireless data receiver, a wireless video data receiver, and the like. The transmitter 1002 is further configured to receive a measured arrival-to-playout time offset (APTO) value 1005 and an average received rate (ARR) 1007 in a feedback message 1008 from the receiver 1004, initiate decongestion by reducing a sending rate at the transmitter 1002 to a decongestion rate determined based on at least one of the APTO value 1005 and the ARR 1007, and end decongestion transmission at the decongestion rate after a decongestion time determined based on at least one of the APTO value 1005 and the ARR 1007. The APTO value 1005 may be measured at the receiver 1004 using an APTO measurement device 1016. The ARR 1007 may be measured at the receiver 1004 using an ARR measurement device 1018. The feedback message 1008 may be sent from the receiver 1004 using a feedback message sender 1020. The feedback message 1008 may be received at the transmitter 1002 using a feedback message receiver 1014. The sending rate at the transmitter 1002 may be reduced to the decongestion rate using a sending rate adjuster 1010. Ending the decongestion transmission at the decongestion rate after the decongestion time may be determined using a decongestion timer 1012.

In a particular embodiment, the decongestion time 112 of FIG. 1 may be proportional to the APTO value 1005 with a constant of proportionality F, and the decongestion rate 110 may be proportional to the ARR 1007 with a constant of proportionality equal to a ratio of (F−1) to F. In a particular embodiment, the transmitter 1002 may be further configured to receive the APTO value 1005 and the ARR 1007 in a single feedback message 1008 from the receiver 1004, where the transmitter 1002 is further configured to add insertable data distributed over an insertion time period that is proportional to the decongestion time 112 with a constant of proportionality R, and where another rate of sending data is determined based on the ARR 1007 and a product of R and F. In other particular embodiments, the insertion time period may be constant or may be set adaptively based on other measurements or criteria, such as quality of service considerations, total network usage, the number of users, the amount of usage per user, and the like.

The transmitter 1002 may include a memory 1028 and a cache memory 1030, which are coupled to a processor, such as a digital signal processor (DSP) 1024. The memory 1028 or the cache memory 1030 may include computer executable instructions that are operative to cause a computer, such as the digital signal processor 1024, to perform various operations. A coder/decoder (CODEC) 1026 may also be coupled to the digital signal processor 1024. A wireless controller 1022 may be coupled to the digital signal processor **1024** and to a wireless antenna (not shown). An input/output device **1032** may also be coupled to the digital signal processor **1024**. The sending rate adjuster **1010** and the decongestion timer **1012** may be implemented in hardware, such as by dedicated circuitry, or may be executed by the digital signal processor **1024**.

The receiver **1004** may include a memory **1040** and a cache memory **1042**, which are coupled to a processor, such as a digital signal processor (DSP) **1036**. The memory **1040** or the cache memory **1042** may include computer executable instructions that are operative to cause a computer, such as the digital signal processor **1036**, to perform various operations, such as generating the feedback message **1008**. A coder/decoder (CODEC) **1038** may also be coupled to the digital signal processor **1036**. A wireless controller **1034** may be coupled to the digital signal processor **1036** and to a wireless antenna (not shown). An input/output device **1044** may also be coupled to the digital signal processor **1036**. The APTO measurement device **1016** and the ARR measurement device **1018** may be implemented in hardware, such as by dedicated circuitry, or may be executed by the digital signal processor **1036**.

Those of skill would further appreciate that the various illustrative logical blocks, configurations, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, configurations, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may include instructions executed by a processor that reside in random access memory (RAM), flash memory, read-only memory (ROM), programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), registers, hard disk, a removable disk, a compact disk read-only memory (CD-ROM), or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an application-specific integrated circuit (ASIC). The ASIC may reside in a computing device or a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a computing device or user terminal.

The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the disclosed embodiments. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the disclosure. Thus, the present disclosure is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope possible consistent with the principles and novel features as defined by the following claims.

The invention claimed is:

1. A method comprising:

receiving a feedback message at a transmitter, the feedback message including an indication of a magnitude of congestion and a sustainable rate of data transmission at a receiver;

determining a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion when the magnitude of congestion satisfies a threshold value;

sending data at the decongestion rate from the transmitter to the receiver for the decongestion time; and

adjusting a data transmission rate at the transmitter to the sustainable rate of data transmission after the decongestion time is ended;

wherein the magnitude of congestion is measured by an arrival-to-playout time offset (APTO) value and the sustainable rate of data transmission is measured by an average received rate (ARR) of data received at the receiver.

2. The method of claim **1**, wherein sending the data from the transmitter to the receiver at the decongestion rate for the decongestion time removes an amount of congested data, the amount of congested data removed being substantially equal to a product of the decongestion time and a difference between the ARR and the decongestion rate.

3. The method of claim **1**, wherein the decongestion time is proportional to the APTO value with a constant of proportionality F.

4. The method of claim **1**, further comprising:

increasing the transmission rate of the transmitter to a rate higher than the sustainable rate of data transmission when the magnitude of congestion is less than the threshold value.

5. A method comprising:

identifying congestion in a transmission path between a sender and a receiver using parameters provided in a feedback message from the receiver to the sender, the parameters including a magnitude of congestion and a sustainable rate of data transmission;

determining a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion;

decongesting the transmission path by sending data at the decongestion rate from the sender to the receiver for the decongestion time; and

adjusting a data transmission rate in the transmission path to the sustainable rate of data transmission after the decongestion time is ended;

wherein the magnitude of congestion is an arrival-to-playout time offset (APTO) value measured at the receiver; and

the sustainable rate of data transmission is an average received rate (ARR) of data transmission of data received at the receiver.

6. A method comprising:

receiving a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR) in a feedback message at a transmitter;

increasing a sending rate at the transmitter to an increased sending rate determined based on at least one of the APTO value and the ARR; and continuing transmission at the increased sending rate after a detection time, wherein the detection time is determined based on at least one of the APTO value, the ARR, a constant value, or an adaptively set value.

7. The method of claim **6**, further comprising:

determining a quantity of insertable data that can be inserted into a transmission path before the transmission path starts to become congested, wherein insertion of the insertable data into the transmission path is distributed over a time period that is proportional to the detection time with a constant of proportionality R.

8. The method of claim **6**, further comprising:

adding insertable data distributed over a data insertion time period that is proportional to the detection time with a constant of proportionality R, wherein the detection time is proportional to the APTO value with a constant of proportionality F, wherein the increased sending rate is determined based on the ARR and a product of R and F.

9. A non-transitory computer-readable medium including computer executable instructions that are operative to cause the computer to:

send a feedback message from a receiver to a transmitter, the feedback message including a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR);

receive data at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO value and the ARR for a decongestion time determined based on at least one of the APTO value and the ARR; and

receive data at the receiver sent by the transmitter at the maximum sustained data rate of the ARR after the decongestion time is ended.

10. The non-transitory computer-readable medium of claim **9**, wherein the decongestion time is proportional to the APTO value with a constant of proportionality F, and the decongestion rate is proportional to the ARR with a constant of proportionality equal to a ratio of (F−1) to F.

11. The non-transitory computer-readable medium of claim **10**, wherein the computer executable instructions are further operative to cause the computer to receive additional inserted data at the receiver, the additional inserted data received during an insertion time period.

12. A method comprising:

sending a feedback message from a receiver to a transmitter, the feedback message including a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR);

receiving data at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO value and the ARR for a decongestion time determined based on at least one of the APTO value and the ARR; and

receiving data at the receiver sent by the transmitter at the maximum sustained data rate of the ARR after the decongestion time is ended.

13. The method of claim **12**, wherein the decongestion time is proportional to the APTO value with a constant of proportionality F, and the decongestion rate is proportional to the ARR with a constant of proportionality equal to a ratio of (F−1) to F.

14. An apparatus comprising:

means for sending a feedback message from a receiver to a transmitter, the feedback message including a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR);

means for receiving data at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO value and the ARR for a decongestion time determined based on at least one of the APTO value and the ARR; and

means for receiving data at the receiver sent by the transmitter at the maximum sustained data rate of the ARR after the decongestion time is ended.

15. The apparatus of claim **14**, wherein the decongestion time is proportional to the APTO value with a constant of proportionality F, and the decongestion rate is proportional to the ARR with a constant of proportionality equal to a ratio of (F−1) to F.

16. An apparatus comprising:

a processor configured to generate a feedback message to send from a receiver to a transmitter, the feedback message including a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR);

wherein data is received at the receiver sent by the transmitter at a decongestion rate determined based on at least one of the APTO value and the ARR for a decongestion time determined based on at least one of the APTO value and the ARR; and

wherein data is received at the receiver sent by the transmitter at the maximum sustained data rate of the ARR after the decongestion time is ended.

17. The apparatus of claim **16**, wherein the decongestion time is proportional to the APTO value with a constant of proportionality F, and the decongestion rate is proportional to the ARR with a constant of proportionality equal to a ratio of (F−1) to F.

18. An apparatus comprising:

a transmitter configured to transmit data, to receive a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR) in a feedback message, to initiate decongestion by reducing a sending rate at the transmitter to a decongestion rate determined based on at least one of the APTO value and the ARR, and to end decongestion transmission at the decongestion rate after a decongestion time determined based on at least one of the APTO value and the ARR.

19. The apparatus of claim **18**, wherein the decongestion time is proportional to the APTO value with a constant of proportionality F, and the decongestion rate is proportional to the ARR with a constant of proportionality equal to a ratio of (F−1) to F.

20. The apparatus of claim **19**, wherein the transmitter is further configured to receive the APTO value and the ARR in a single feedback message, wherein the transmitter is further configured to add insertable data distributed over an insertion time period that is proportional to the decongestion time with a constant of proportionality R, and wherein another rate of sending data is determined based on the ARR and a product of R and F.

21. An apparatus comprising:

means for initiating decongestion by reducing a sending rate at a transmitter to a decongestion rate determined based on at least one of a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR) that are received in a feedback message; and

means for ending decongestion transmission at the decongestion rate after a decongestion time determined based on at least one of the APTO value and the ARR.

22. The apparatus of claim **21**, wherein the decongestion time is proportional to the APTO value with a constant of proportionality F, and the decongestion rate is proportional to the ARR with a constant of proportionality equal to a ratio of (F−1) to F.

23. An apparatus comprising:

means for receiving a feedback message at a transmitter, the feedback message including an indication of a magnitude of congestion and a sustainable rate of data transmission at a receiver;

means for determining a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion when the magnitude of congestion satisfies a threshold value;

means for sending data at the decongestion rate from the transmitter to the receiver for the decongestion time; and

means for adjusting a data transmission rate at the transmitter to the sustainable rate of data transmission after the decongestion time is ended, wherein the magnitude of congestion is an arrival-to-playout time offset (APTO) value measured at the receiver and the sustainable rate of data transmission is an average received rate (ARR) of data transmission of data received at the receiver.

24. A non-transitory computer-readable medium including computer executable instructions that are operative to cause the computer to:

receive a feedback message at a transmitter, the feedback message including an indication of a magnitude of congestion and a sustainable rate of data transmission at a receiver;

determine a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion when the magnitude of congestion satisfies a threshold value;

send data at the decongestion rate from the transmitter to the receiver for the decongestion time; and

adjust a data transmission rate at the transmitter to the sustainable rate of data transmission after the decongestion time is ended, wherein the magnitude of congestion is an arrival-to-playout time offset (APTO) value measured at the receiver and the sustainable rate of data transmission is an average received rate (ARR) of data transmission of data received at the receiver.

25. An apparatus comprising:

a feedback message receiver configured to receive a feedback message at a transmitter, the feedback message including an indication of a magnitude of congestion and a sustainable rate of data transmission at a receiver; and

a processor configured to:

determine a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion when the magnitude of congestion satisfies a threshold value;

send data at the decongestion rate from the transmitter to the receiver for the decongestion time; and

adjust a data transmission rate at the transmitter to the sustainable rate of data transmission after the decongestion time is ended, wherein the magnitude of congestion is an arrival-to-playout time offset (APTO) value measured at the receiver and the sustainable rate of data transmission is an average received rate (ARR) of data transmission of data received at the receiver.

26. An apparatus comprising:

means for identifying congestion in a transmission path between a sender and a receiver using parameters provided in a feedback message from the receiver to the sender, the parameters including a magnitude of congestion and a sustainable rate of data transmission;

means for determining a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion;

means for decongesting the transmission path by sending data at the decongestion rate from the sender to the receiver for the decongestion time; and

means for adjusting a data transmission rate in the transmission path to the sustainable rate of data transmission after the decongestion time is ended, wherein the magnitude of congestion is an arrival-to-playout time offset (APTO) value measured at the receiver and the sustainable rate of data transmission is an average received rate (ARR) of data transmission of data received at the receiver.

27. A non-transitory computer-readable medium including computer executable instructions that are operative to cause the computer to:

identify congestion in a transmission path between a sender and a receiver using parameters provided in a feedback message from the receiver to the sender, the parameters including a magnitude of congestion and a sustainable rate of data transmission;

determine a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion;

decongest the transmission path by sending data at the decongestion rate from the sender to the receiver for the decongestion time; and

adjust a data transmission rate in the transmission path to the sustainable rate of data transmission after the decongestion time is ended, wherein the magnitude of congestion is an arrival-to-playout time offset (APTO) value measured at the receiver and the sustainable rate of data transmission is an average received rate (ARR) of data transmission of data received at the receiver.

28. An apparatus comprising:

a processor configured to:

identify congestion in a transmission path between a sender and a receiver using parameters provided in a feedback message from the receiver to the sender, the parameters including a magnitude of congestion and a sustainable rate of data transmission;

determine a decongestion rate and a decongestion time based on at least one of the sustainable rate of data transmission and the magnitude of congestion;

decongest the transmission path by sending data at the decongestion rate from the sender to the receiver for the decongestion time; and

adjust a data transmission rate in the transmission path to the sustainable rate of data transmission after the decongestion time is ended, wherein the magnitude of congestion is an arrival-to-playout time offset (APTO) value measured at the receiver and the sustainable rate of data transmission is an average received rate (ARR) of data transmission of data received at the receiver.

29. A non-transitory computer-readable medium including computer executable instructions that are operative to cause the computer to:

receive a measured arrival-to-playout time offset (APTO) value and an average received rate (ARR) in a feedback message at a transmitter;

increase a sending rate at the transmitter to an increased sending rate determined based on at least one of the APTO value and the ARR; and

continue transmission at the increased sending rate after a detection time, wherein the detection time is determined based on at least one of the APTO value, the ARR, a constant value, or an adaptively set value.

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