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(54) **DIFFERENTIATION AMONG OCCURRENCES OF PACKET REORDERING, CONGESTIVE PACKET LOSS, OR RANDOM PACKET LOSS IN COMMUNICATION NETWORKS**

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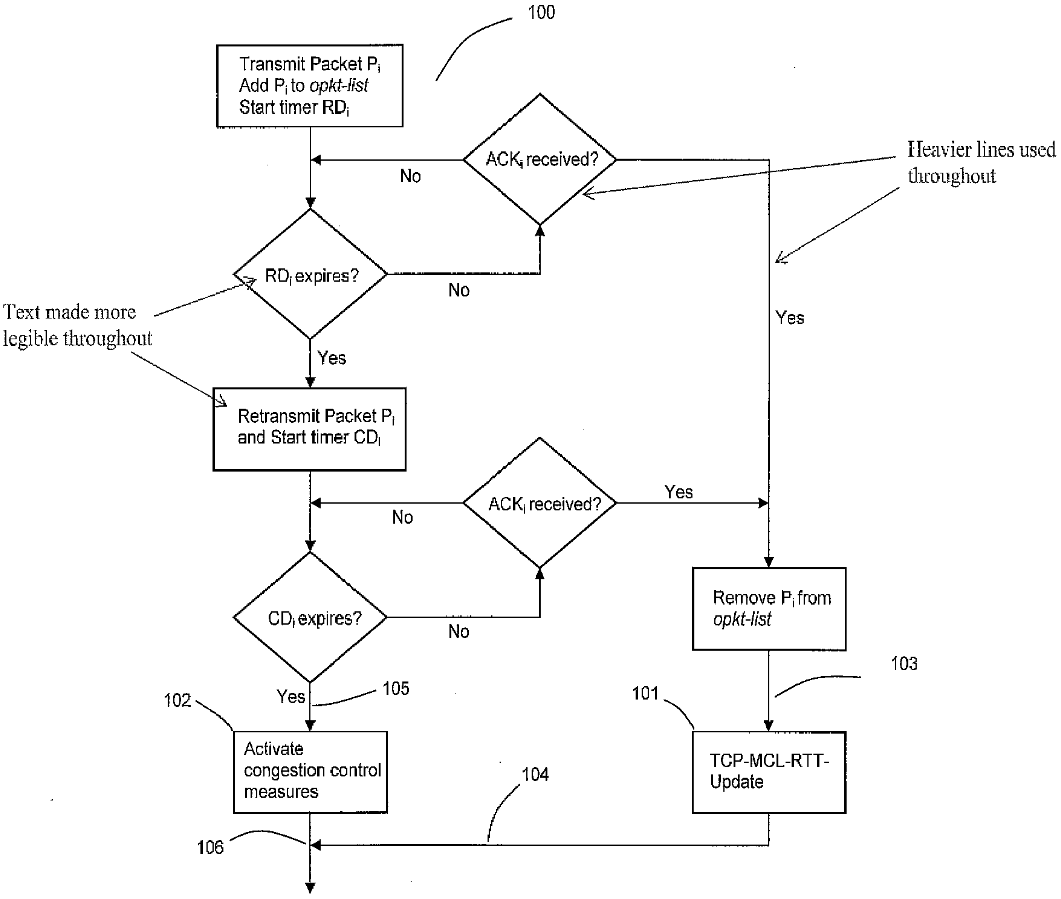
(57) **ABSTRACT**

Example embodiments disclosed herein may relate to differentiating among network congestion, packet reordering, or random packet loss in wireless networks.



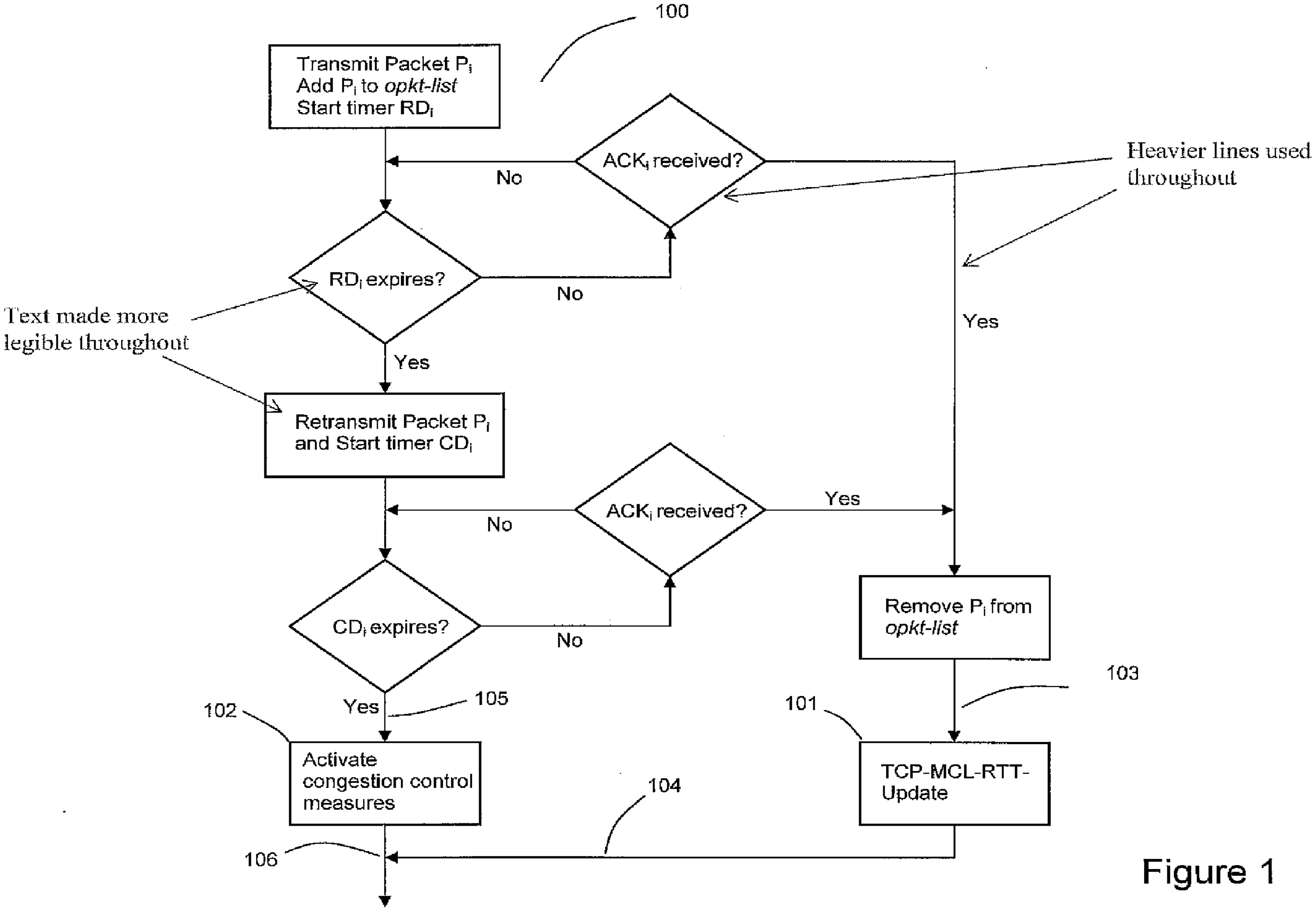


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Figure 1

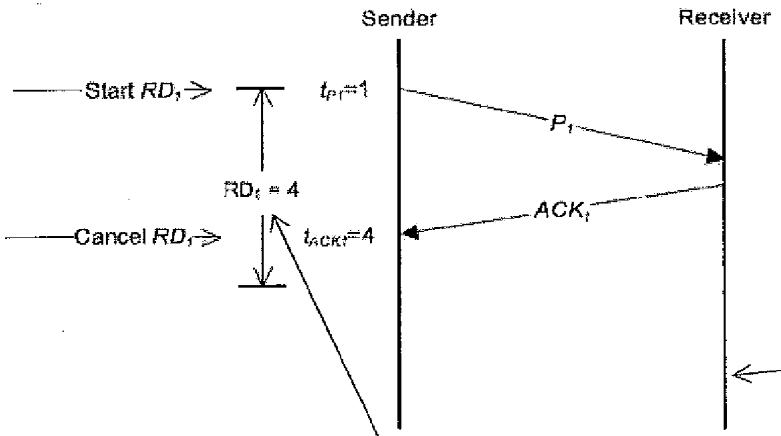

Figure 2a

Heavier lines used throughout

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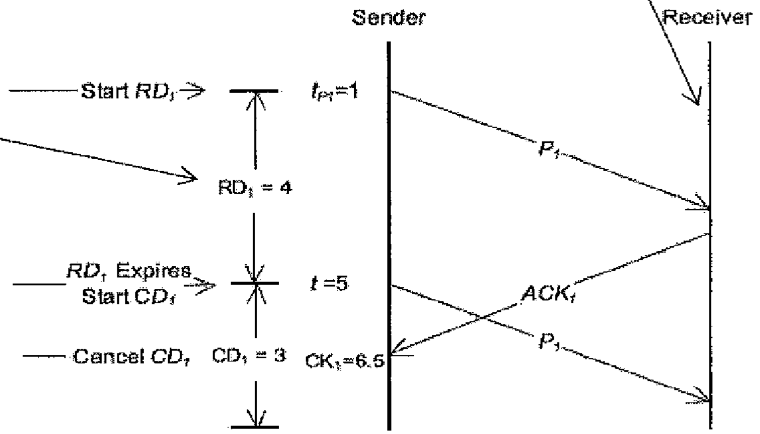

Figure 2b

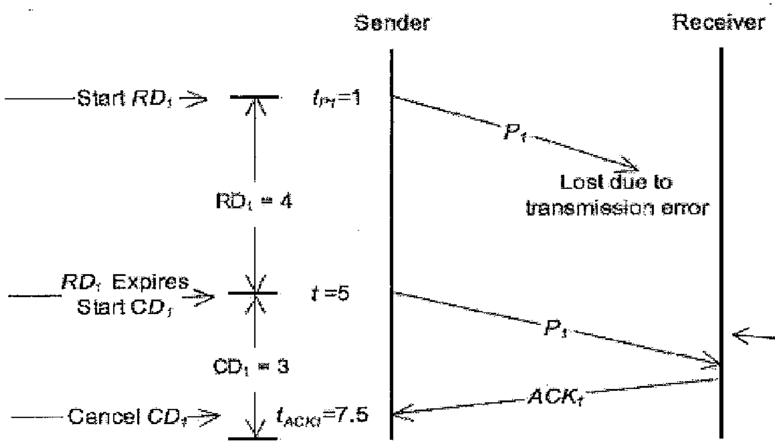

Figure 2c

Heavier lines used throughout

Text made more legible throughout

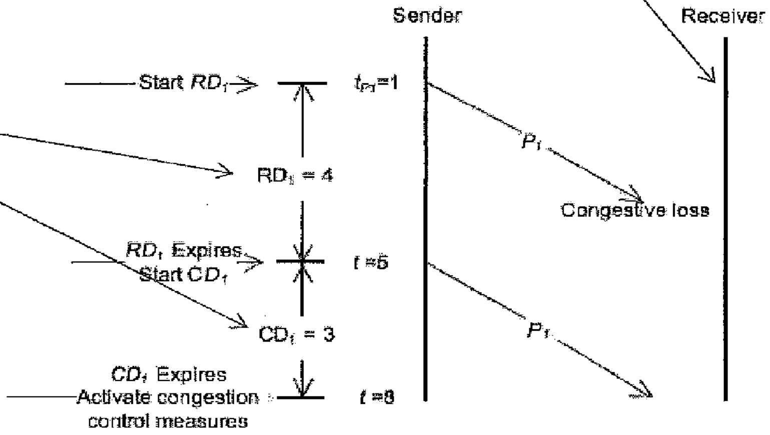

Figure 2d

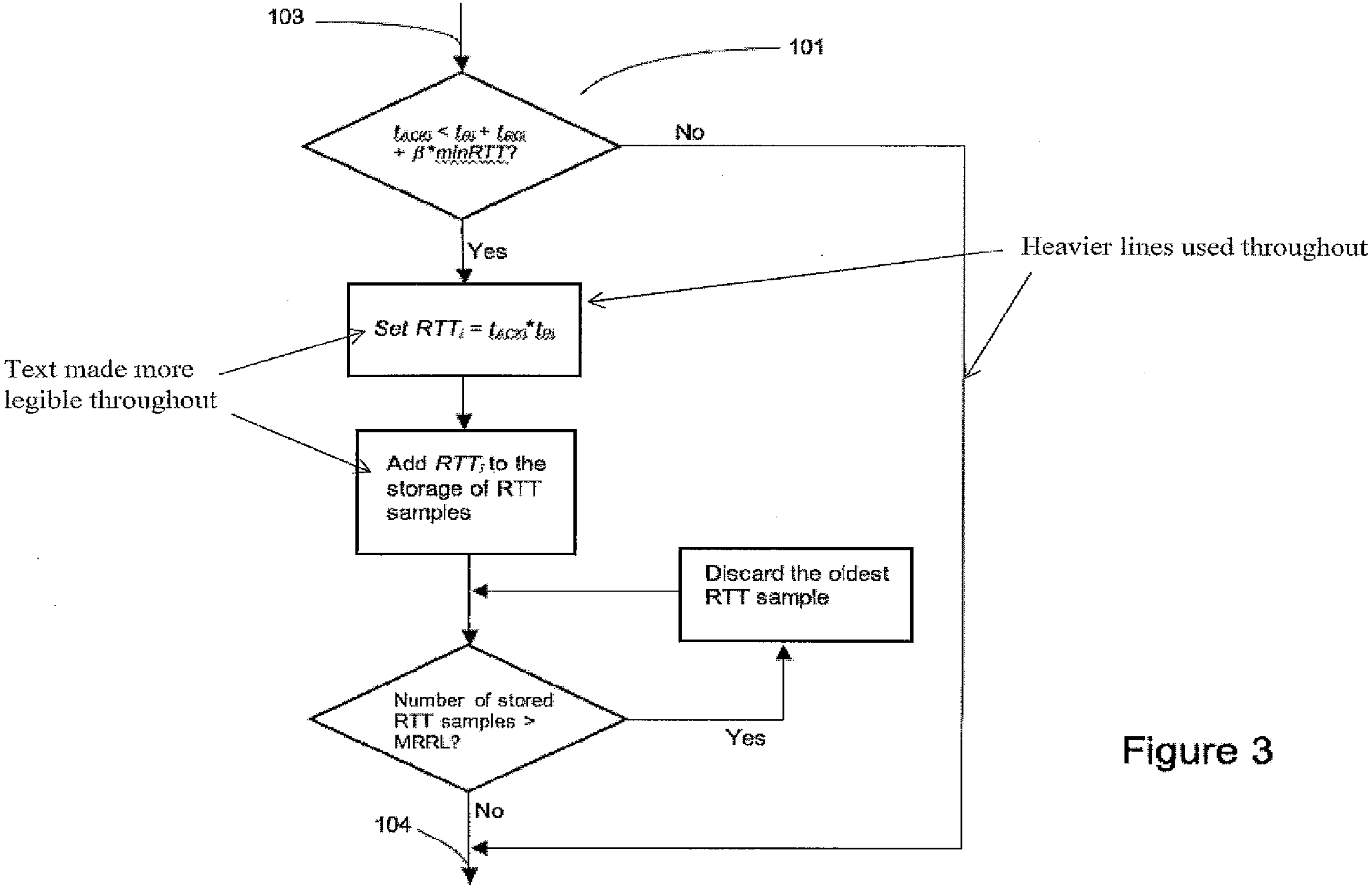
103
101
$t_{ACKi} < t_{Bi} + t_{ACKi}$
$+ \beta * minRTT?$
No
Yes
Heavier lines used throughout
Set $RTT_i = t_{ACKi} * t_{Bi}$
Text made more legible throughout
Add RTT_i to the storage of RTT samples
Discard the oldest RTT sample
Number of stored RTT samples > MRRL?
Yes
No
104

Figure 3

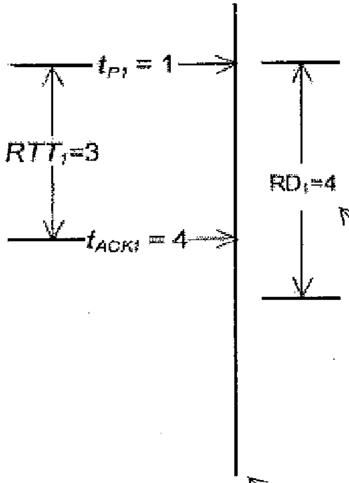

Figure 4a

Text made more legible throughout

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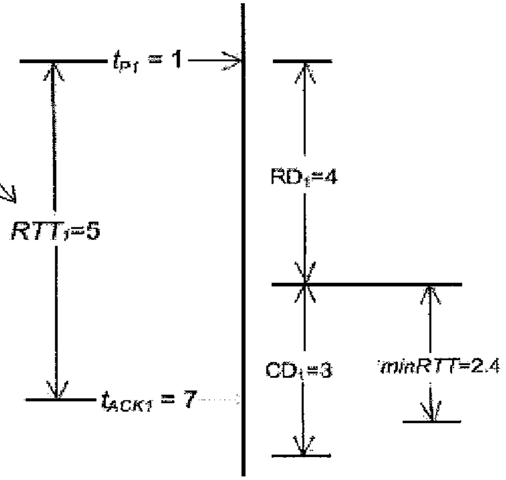

Figure 4b

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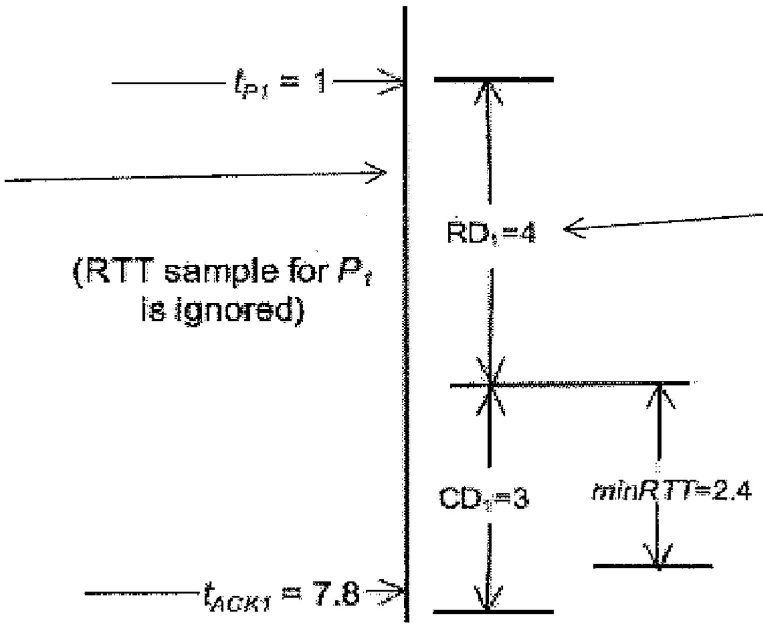

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Figure 4c

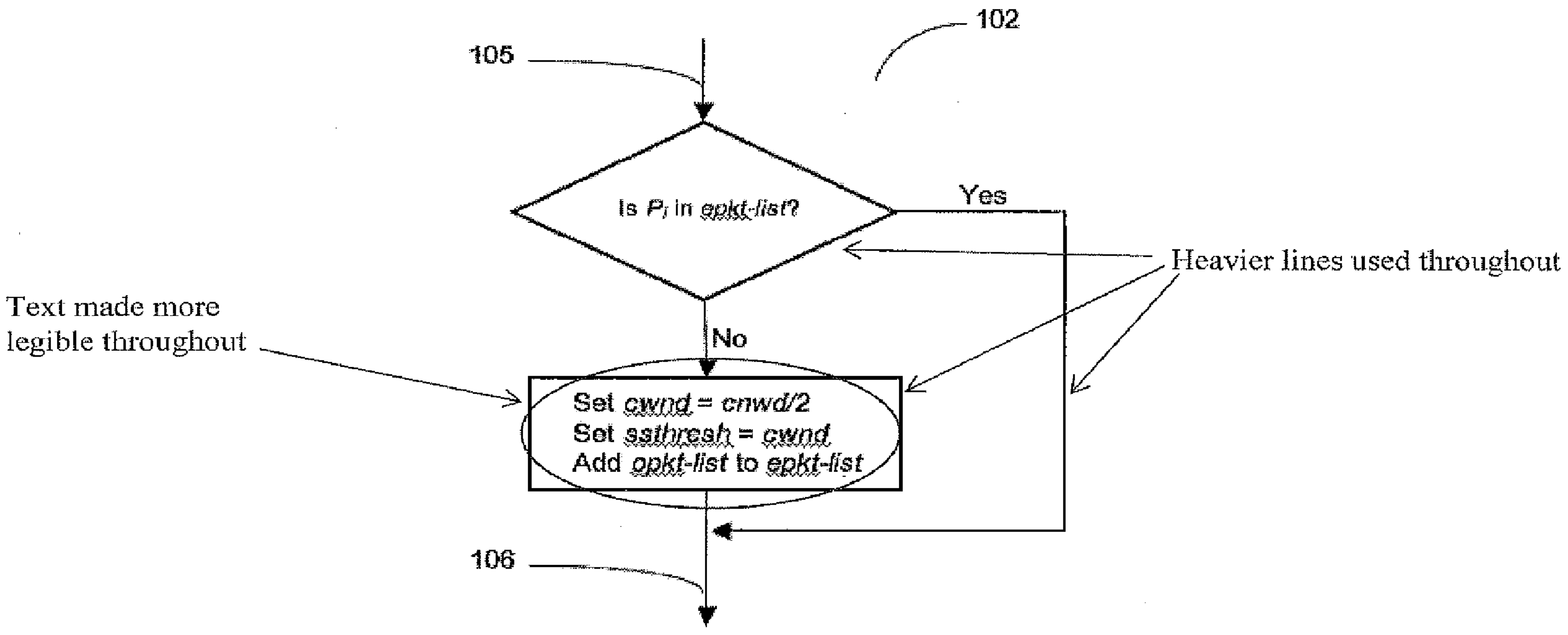
102
105
Is P_i in epkt-list?
Yes
No
Heavier lines used throughout
Text made more legible throughout
Set cwnd = cnwd/2
Set ssthresh = cwnd
Add opkt-list to epkt-list
106

Figure 5

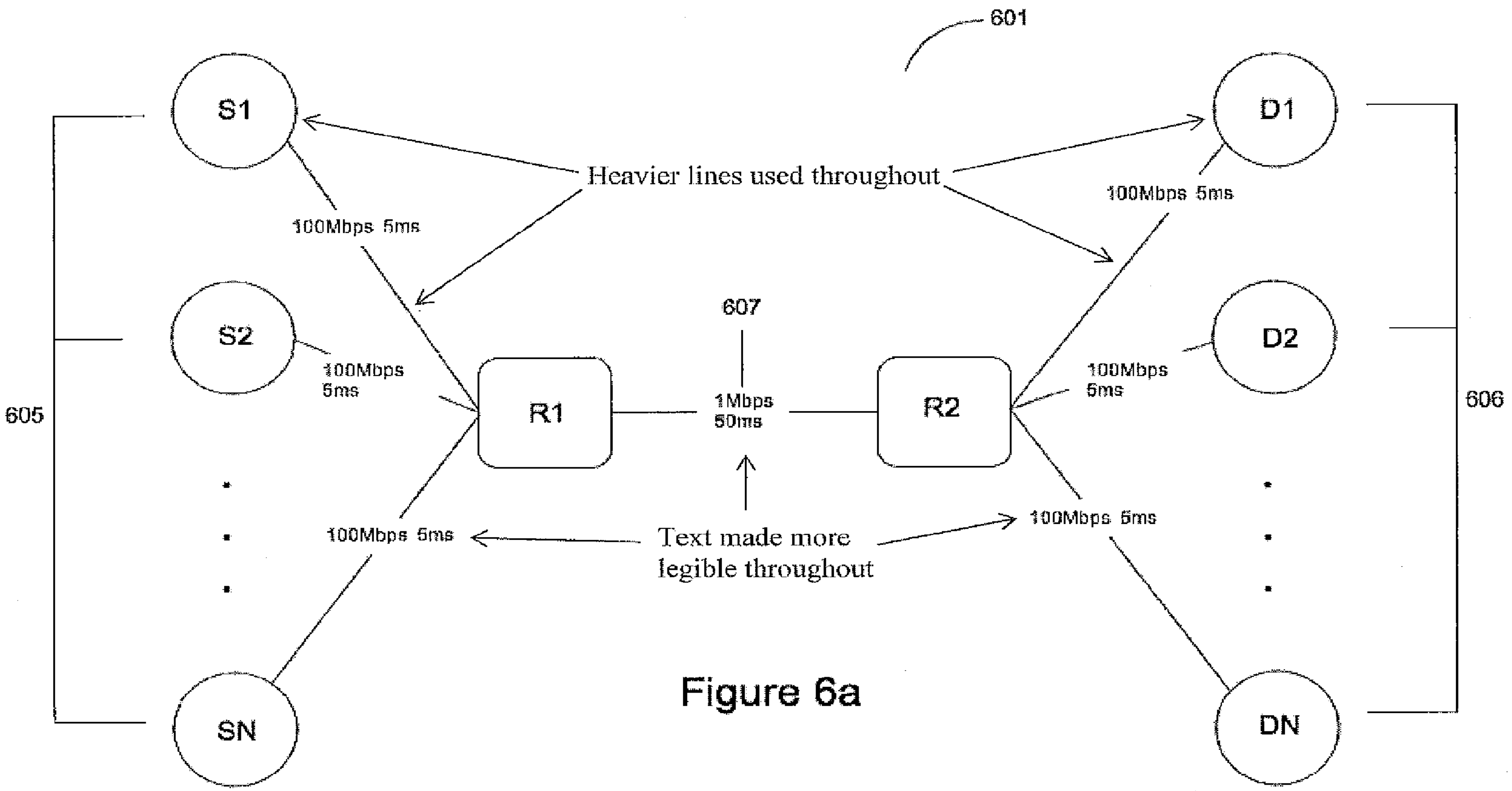
601
S1
S2
SN
D1
D2
DN
R1
R2
605
606
607
100Mbps 5ms
100Mbps 5ms
100Mbps 5ms
100Mbps 5ms
100Mbps 5ms
100Mbps 5ms
1Mbps 50ms
Heavier lines used throughout
Text made more legible throughout

Figure 6a

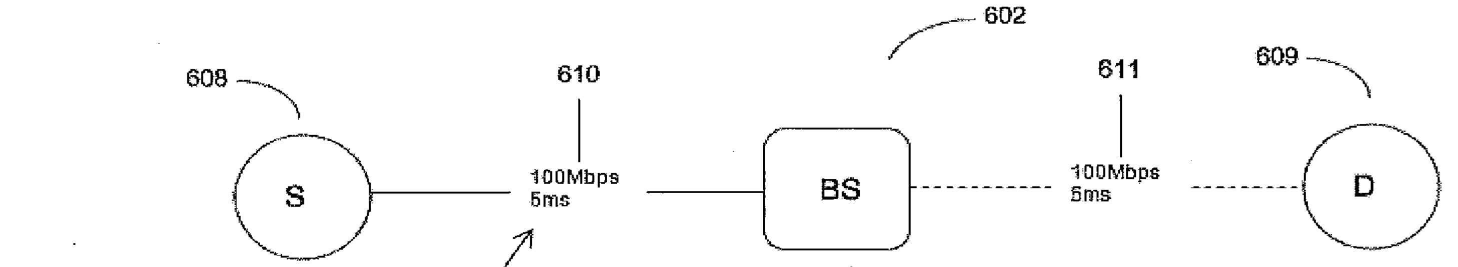

Figure 6b

Text made more legible throughout

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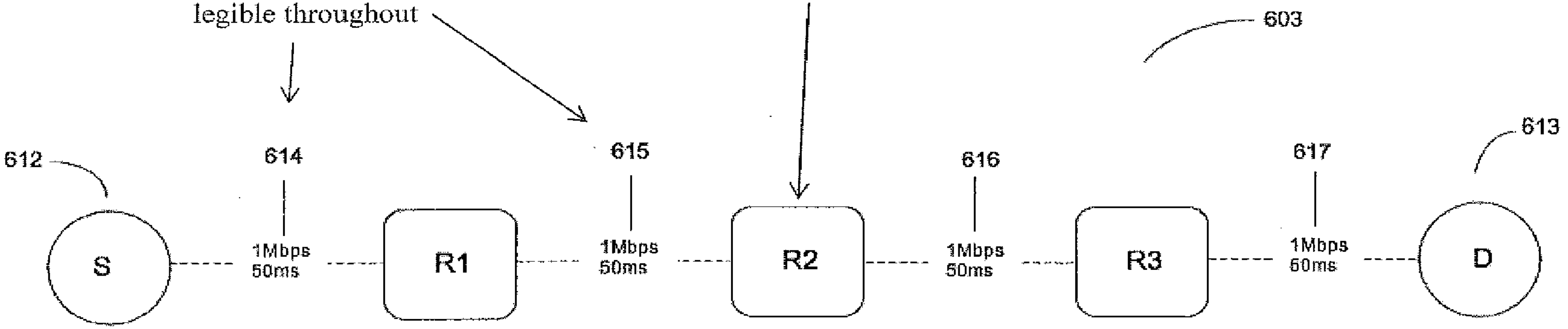

Figure 6c

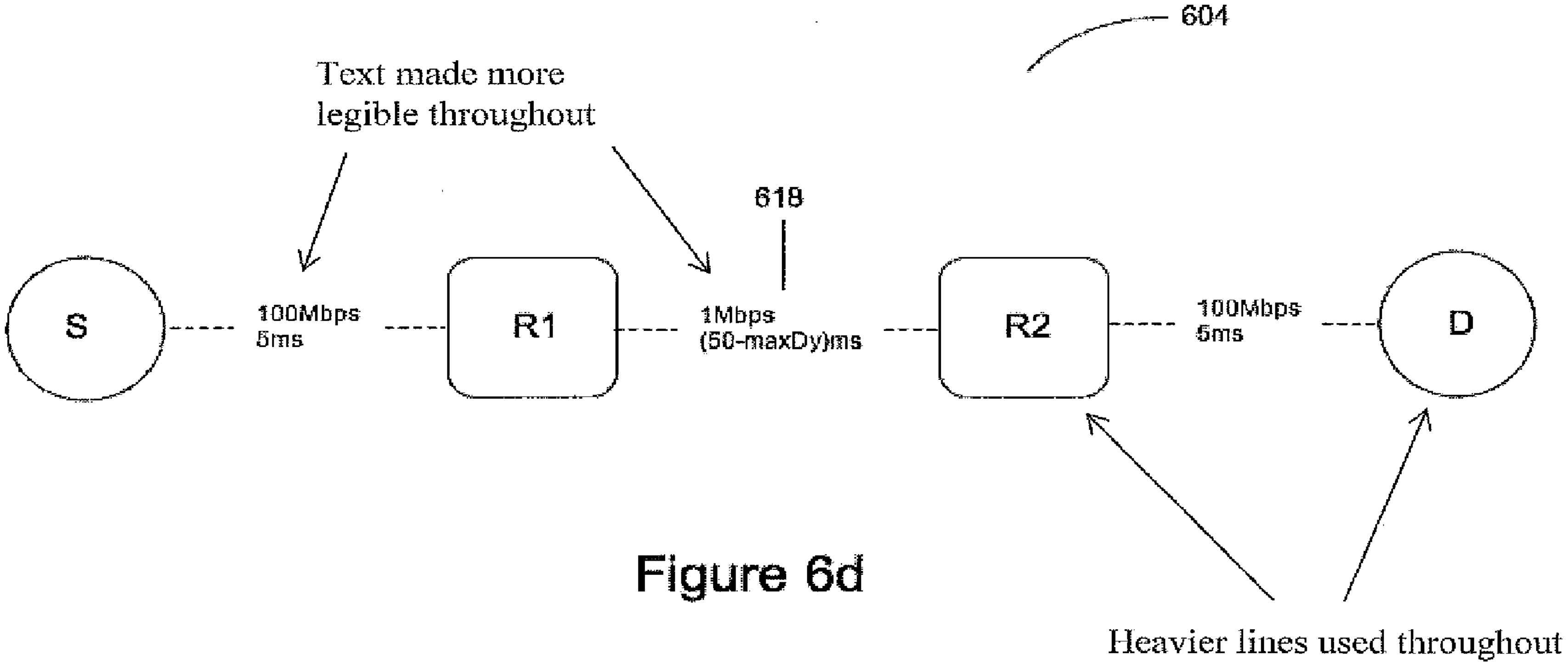
604
Text made more legible throughout
618
S
100Mbps
5ms
R1
1Mbps
(50-maxDy)ms
R2
100Mbps
5ms
D
Heavier lines used throughout

Figure 6d

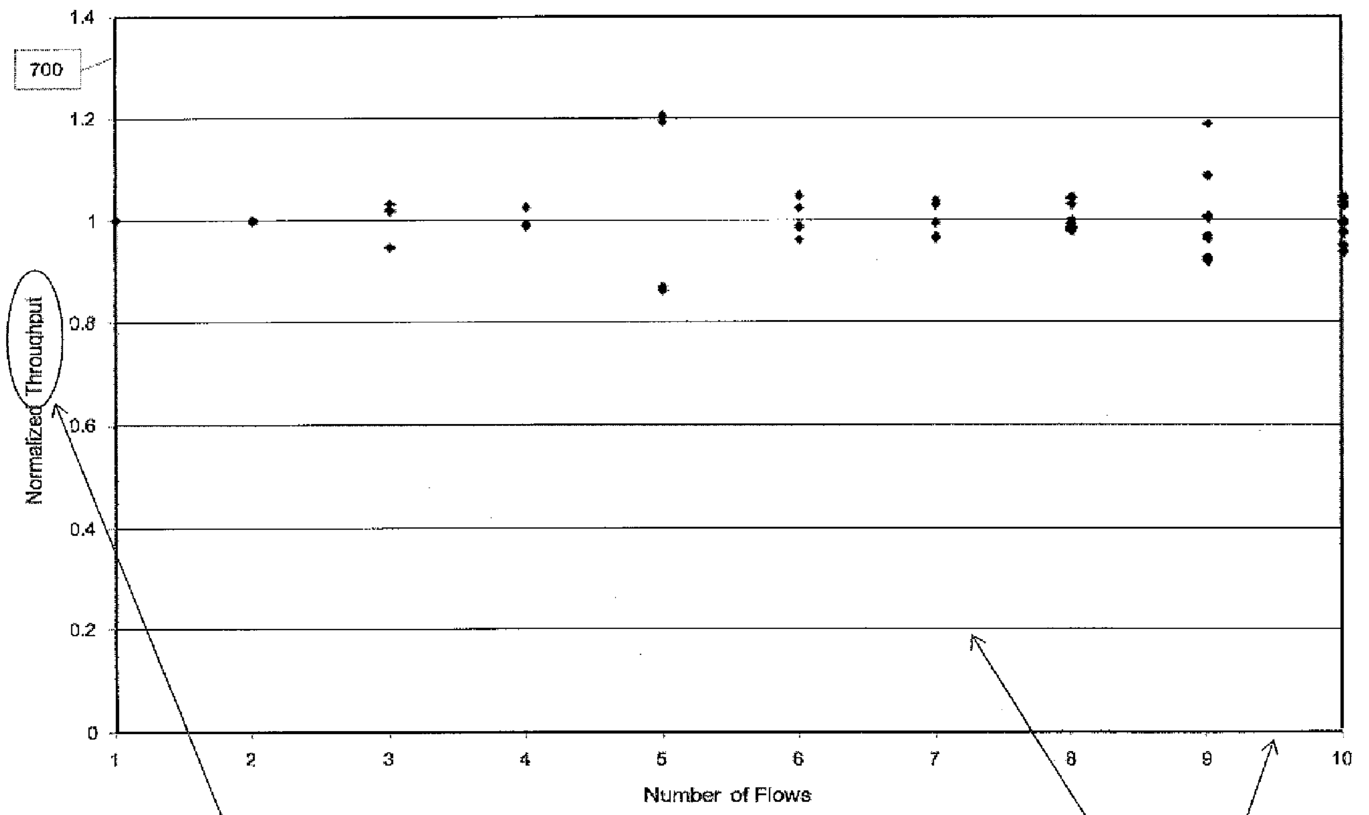

Figure 7

Typographical error corrected - "Goodput" changed to "Throughput"; Text made more legible throughout

Heavier lines used throughout

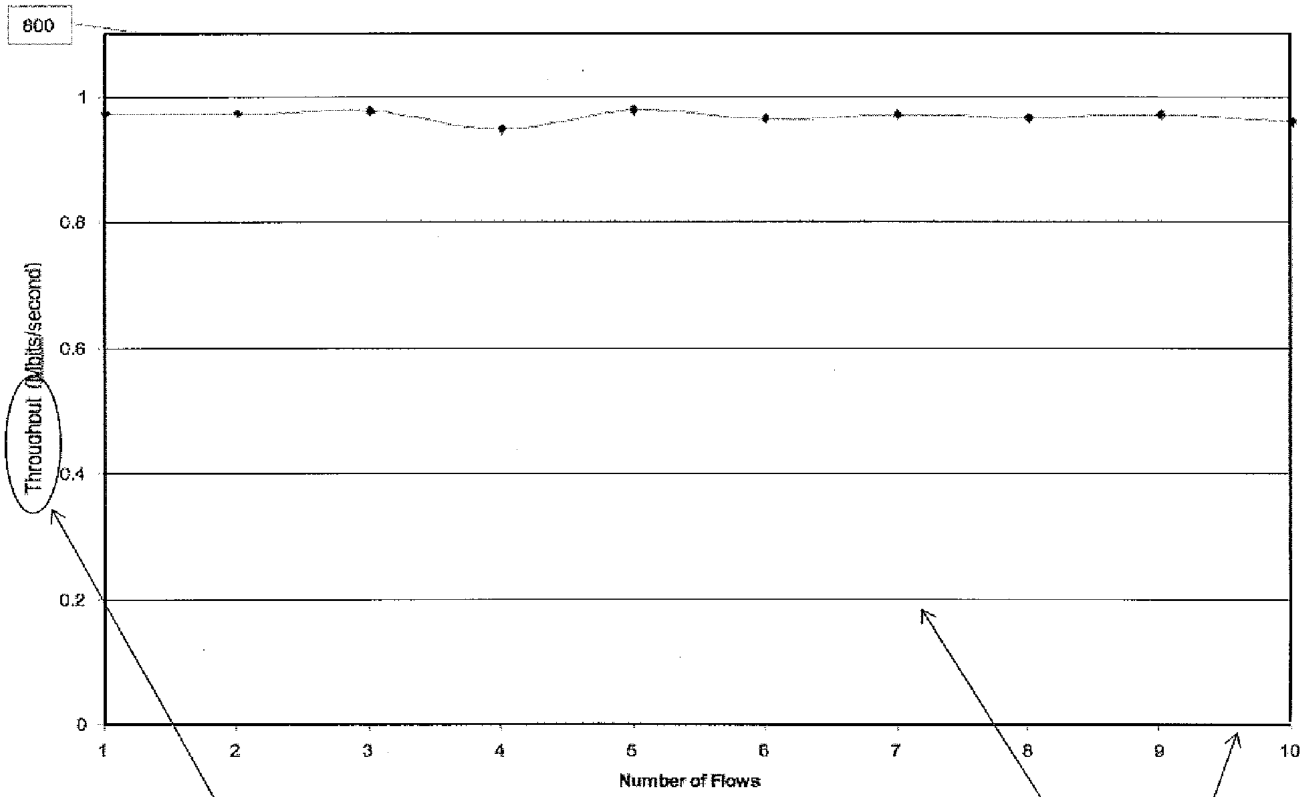

Figure 8

Typographical error corrected - "Goodput" changed to "Throughput"; Text made more legible throughout

Heavier lines used throughout

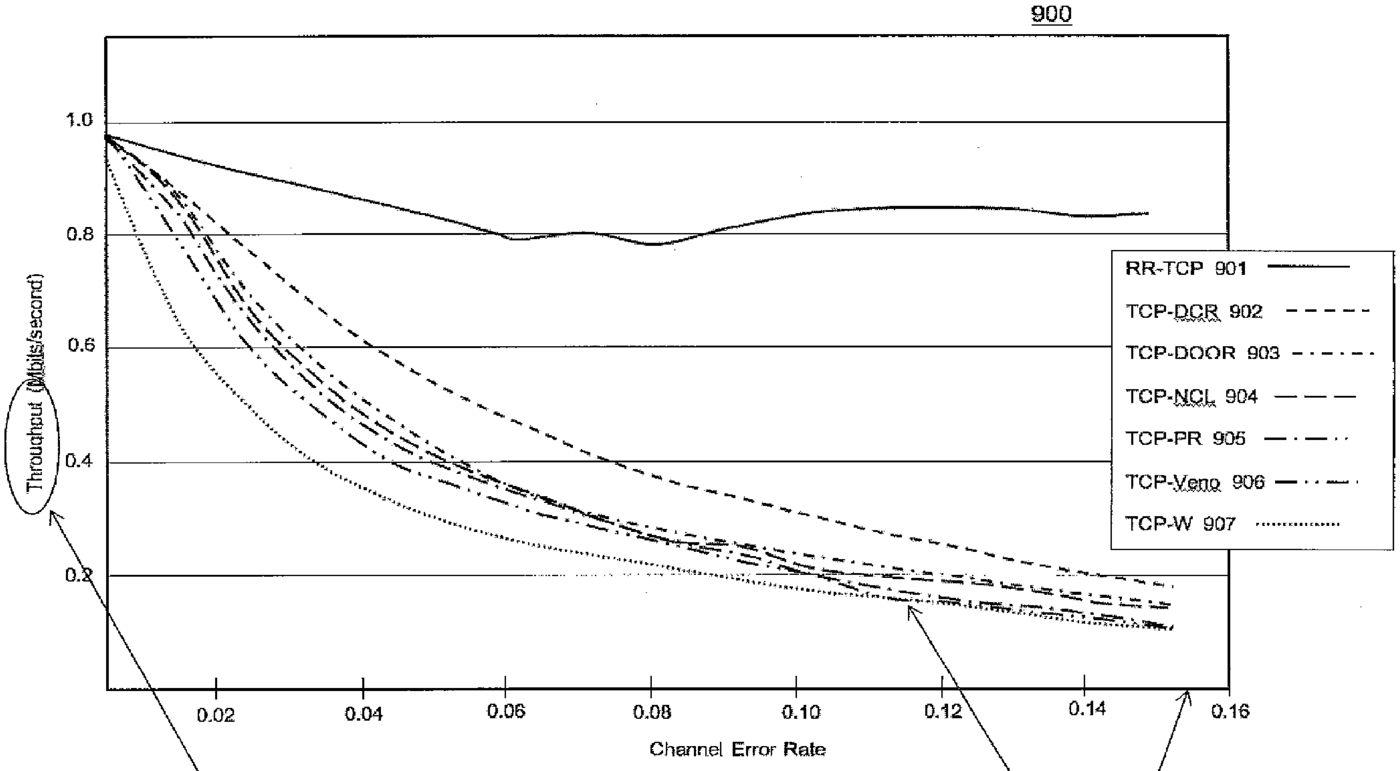

Figure 9

Typographical error corrected - "Goodput" changed to "Throughput"; Text made more legible throughout

Heavier lines used throughout

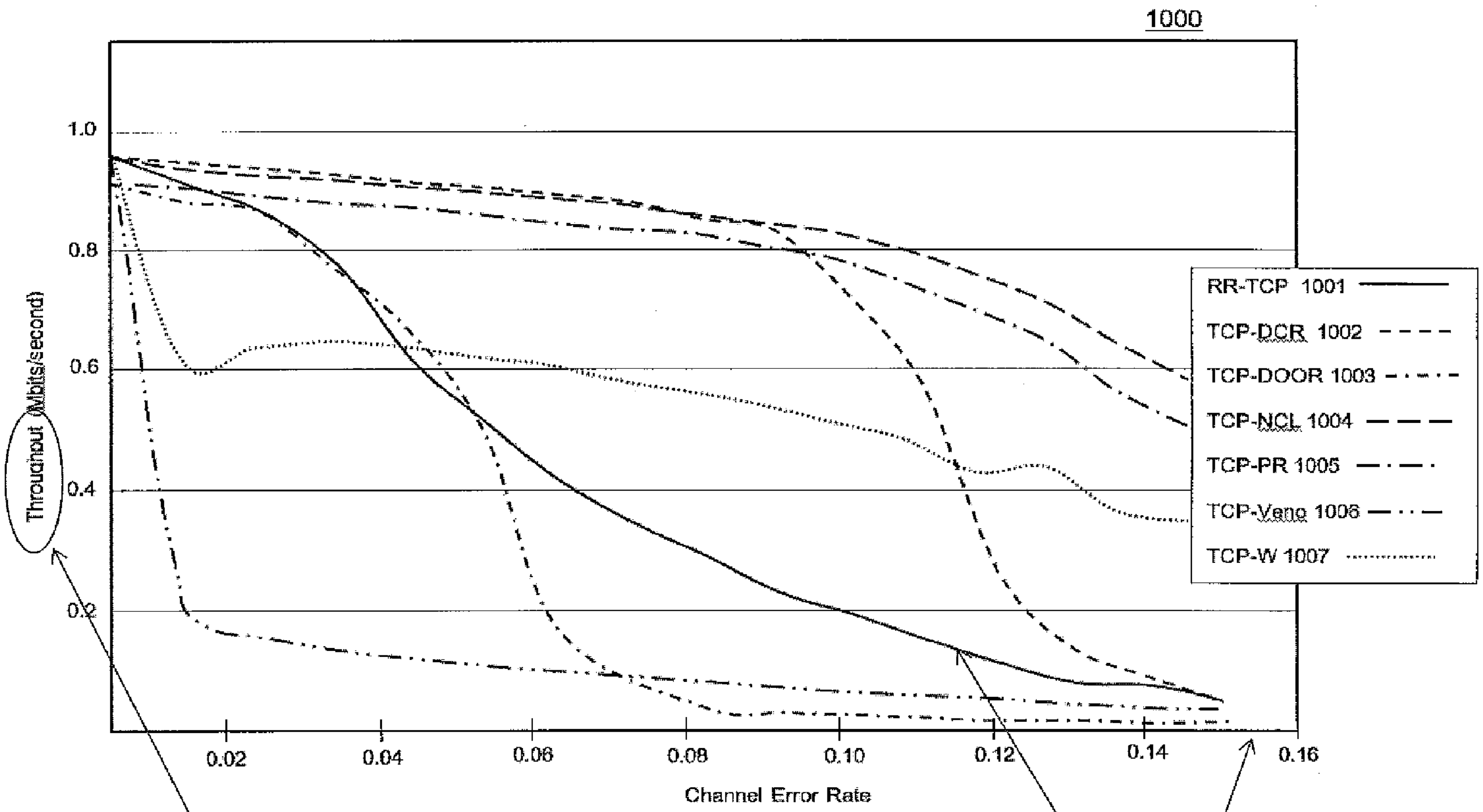

Figure 10

Typographical error corrected - "Goodput" changed to "Throughput"; Text made more legible throughout

Heavier lines used throughout

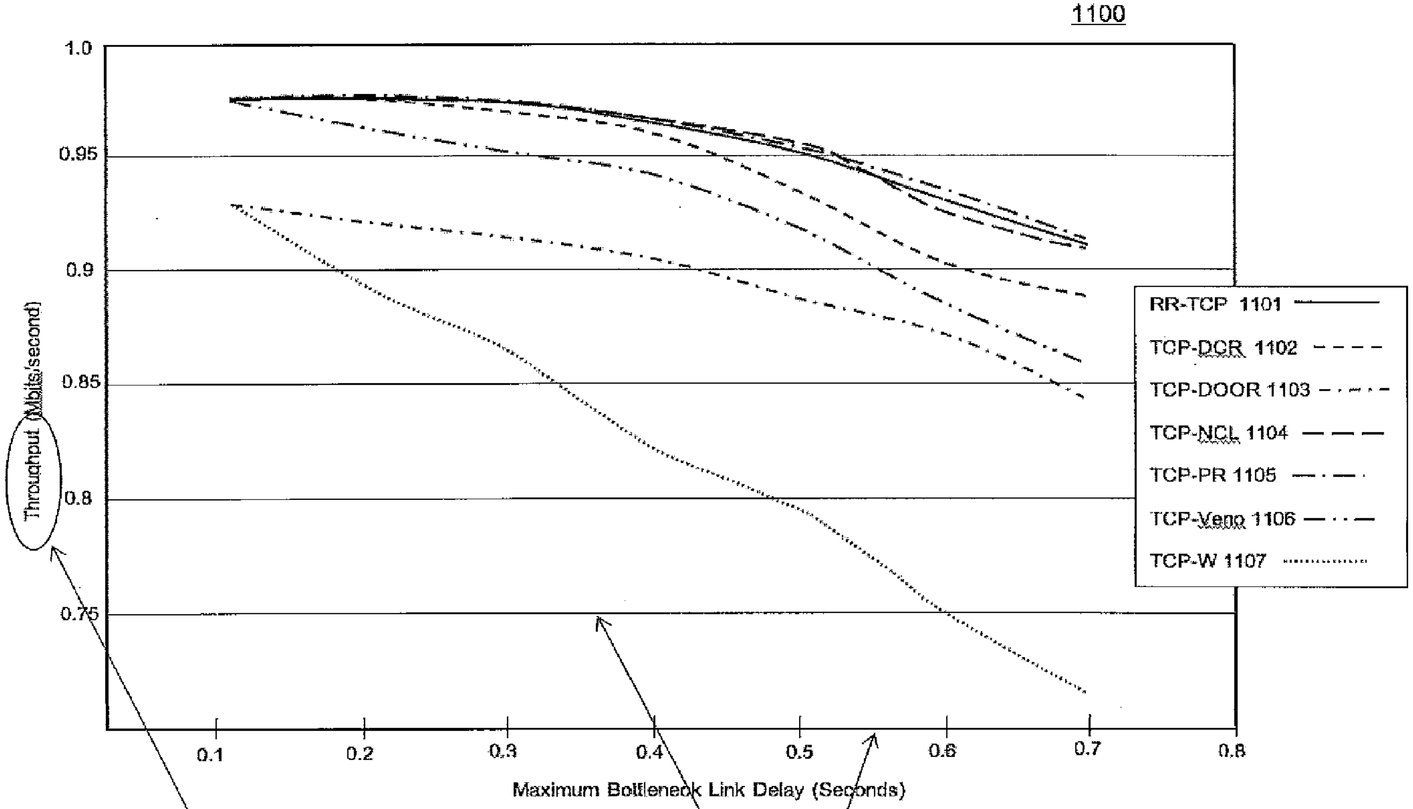

Figure 11

Typographical error corrected - "Goodput" changed to "Throughput"; Text made more legible throughout

Heavier lines used throughout

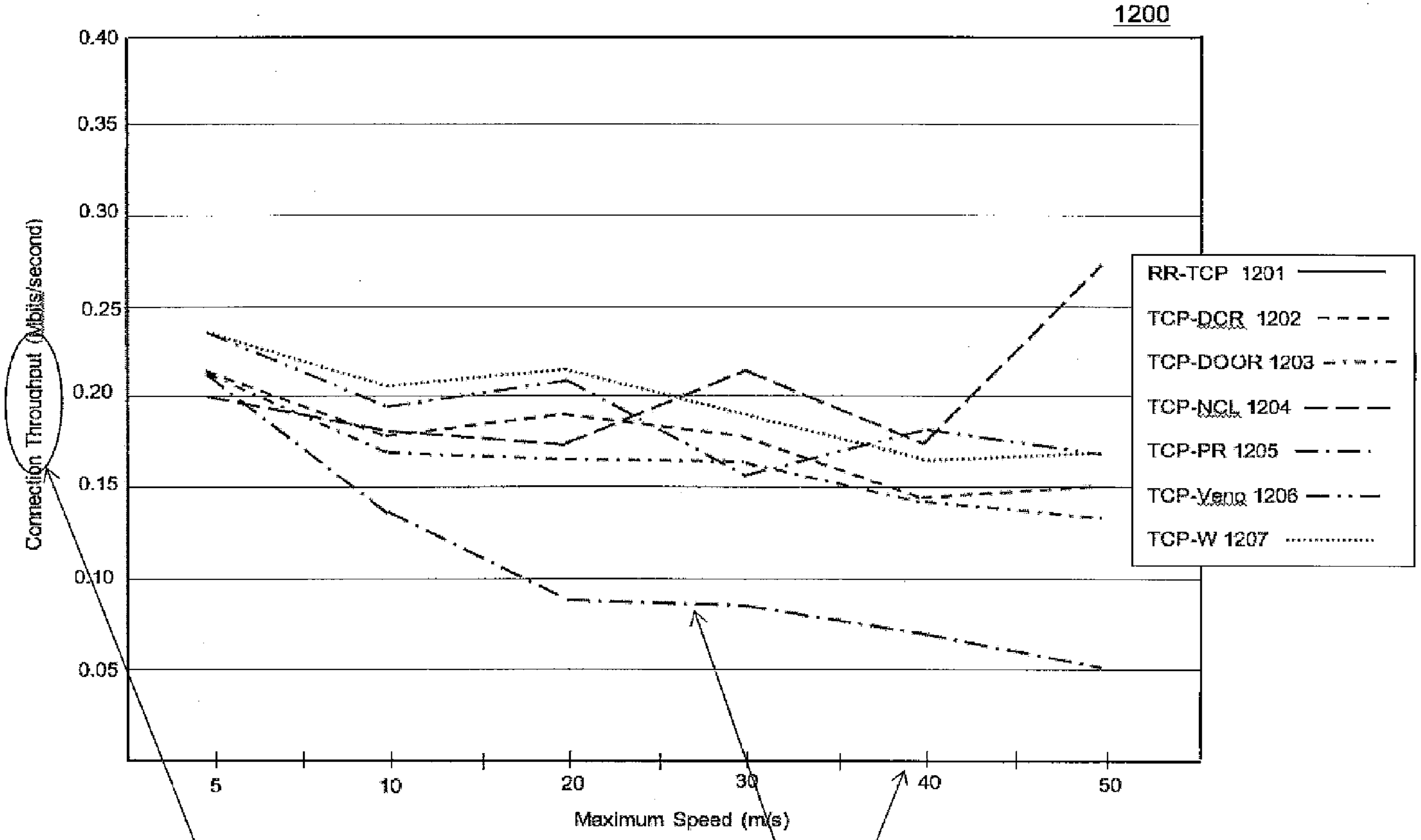

Figure 12

Typographical error corrected - "Goodput" changed to "Throughput"; Text made more legible throughout

Heavier lines used throughout

DIFFERENTIATION AMONG OCCURRENCES OF PACKET REORDERING, CONGESTIVE PACKET LOSS, OR RANDOM PACKET LOSS IN COMMUNICATION NETWORKS

[0001] This application claims priority from U.S. Provisional Application Ser. No. 61/241,689, filed Sep. 11, 2009, and entitled "Differentiation Among Occurrences of Packet Reordering, Congestive Packet Loss, and Random Packet Loss In Communication Networks."

BACKGROUND

[0002] 1. Field:

[0003] Subject matter disclosed herein may relate to end-to-end congestion control for wireless networks. More specifically, subject matter disclosed herein may relate to improved differentiation among occurrences of network congestion, packet reordering, or packet loss for wireless networks.

[0004] 2. Information:

[0005] The Transmission Control Protocol (TCP) comprises a transport layer protocol for current networks, providing connection-oriented end-to-end in-order signal delivery services for various applications. Traditionally, design of TCP relies on assumptions of nearly in-order packet delivery or nearly error-free transmission. For example, a TCP receiver would expect sequence numbers of received packets belonging to a particular flow to be consecutively ordered. Otherwise, a TCP receiver may return a duplicate acknowledgment to a corresponding TCP sender for individual received packets failing expectation. At a sender side, if an amount of duplicate acknowledgments exceeds a specified threshold value, various congestion control measures may be activated. A congestion window (cwnd) size may be reduced. Therefore, out-of-order packet events are effectively treated as an indication of network overload.

[0006] However, while network congestion may result in out-of-order packet events over conventional wired networks, wireless networks may experience random packet loss or packet reordering as sources of such events.

[0007] As compared with wired media, a wireless medium may provide much more lossy physical links for signal transmission. Signals propagating over wireless channels may suffer from degradation, interference, or noise. Packets received may be damaged beyond recovery capabilities of error correcting codes, if any, in a receiver. Damaged packets may thus be discarded, leading to occurrences of random packet loss. In wireless networks, random packet loss is not uncommon.

BRIEF DESCRIPTION OF THE FIGURES

[0008] Claimed subject matter is particularly pointed out and distinctly claimed in the concluding portion of the specification. However, both as to organization and/or method of operation, together with objects, features, or advantages thereof, claimed subject matter may be better understood by reference to the following detailed description if read with the accompanying drawings.

[0009] FIG. **1** is a flowchart depicting an example embodiment of a process for activating packet retransmission or congestion control measures.

[0010] FIG. **2***a* is a diagram illustrating an example embodiment of a process for activating packet retransmission or congestion control measures.

[0011] FIG. **2***b* is an illustration depicting an example embodiment of a process for activating packet retransmission or congestion control measures.

[0012] FIG. **2***c* is a diagram illustrating an example embodiment of a process for activating packet retransmission or congestion control measures.

[0013] FIG. **2***d* is an illustration showing an example embodiment of a process for activating packet retransmission or congestion control measures.

[0014] FIG. **3** is a flowchart illustrating an example update process for maintaining storage of round trip time samples for an embodiment.

[0015] FIG. **4***a* is a diagram illustrating an example round trip time update process.

[0016] FIG. **4***b* is an illustration depicting an example round trip time update process.

[0017] FIG. **4***c* is a diagram illustrating an example round trip time update process.

[0018] FIG. **5** is a flowchart illustrating an example process for activating congestion control measures in accordance with an embodiment.

[0019] FIG. **6***a* is a diagram illustrating an example network topology utilized in various simulation experiments.

[0020] FIG. **6***b* is a diagram illustrating an additional example network topology utilized in various simulation experiments.

[0021] FIG. **6***c* is a diagram illustrating an example network topology utilized in various simulation experiments.

[0022] FIG. **6***d* is a diagram illustrating an additional example network topology utilized in various simulation experiments.

[0023] FIG. **7** is a diagram plotting normalized throughput values for a number of example transmission control protocol (TCP) communication flows implemented in accordance with one or more embodiments against a number of communication flows.

[0024] FIG. **8** is a diagram plotting total throughput of all example TCP flows against a number of flows.

[0025] FIG. **9** is a diagram of an example throughput performance comparison of an example protocol implemented in accordance with one or more embodiments with a number of existing TCP variants over an infrastructure-based wireless network.

[0026] FIG. **10** is a diagram depicting an example throughput performance comparison of an example protocol implemented in accordance with one or more embodiments with a number of existing TCP variants over a multi-hop ad-hoc wireless network.

[0027] FIG. **11** is a diagram depicting an example throughput performance comparison of an example protocol implemented in accordance with one or more embodiments with a number of existing TCP variants over a wired network with a bottleneck-link of time-varying delay.

[0028] FIG. **12** is a diagram depicting an example throughput performance comparison of an example protocol implemented in accordance with one or more embodiments with a number of existing TCP variants over a mobile ad-hoc network.

[0029] FIG. **13** is a block diagram depicting an example embodiment of a computing platform.

[0030] Reference is made in the following detailed description to the accompanying drawings, which form a part hereof, wherein like numerals may designate like parts throughout to indicate corresponding or analogous elements. For simplicity or clarity of illustration, elements illustrated in the figures have not necessarily been drawn to scale. For example, dimensions of some elements may be exaggerated relative to other elements for clarity. Further, it is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of claimed subject matter. It should also be noted that directions and references such as, for example, up, down, top, bottom, over, above and so on, may be used to facilitate the discussion of the drawings and are not intended to restrict application of claimed subject matter. Therefore, the following detailed description is not to be taken in a limiting sense and the scope of claimed subject matter is intended to be defined by the appended claims and equivalents.

DETAILED DESCRIPTION

[0031] In the following detailed description, numerous specific details are set forth to provide a thorough understanding of claimed subject matter. However, it will be understood by those skilled in the art that claimed subject matter may be practiced without these specific details. In other instances, methods, apparatuses or systems that would be known by one of ordinary skill have not been described in detail so as not to obscure claimed subject matter.

[0032] Packet reordering refers to disruption in a packet order of a communication flow established in accordance with a communication protocol, such as the Transmission Control Protocol (TCP). Despite conventional beliefs that packet reordering comprises a transient or pathological network behavior, it may be observed over modern networks and may be attributed at least in part to any of a myriad of reasons. Due at least in part to high transmission error rates and, in some cases, mobility in wireless networks, packet reordering may further increase in the event a transmission medium evolves from physical cables to a wireless medium. For example, packet reordering may be commonly observed over wireless networks, including link layer retransmission (LLRTX), path change, or hand-off, described below.

[0033] LLRTX: To address transmission error rates of wireless channels, some link layer retransmission mechanisms have been proposed to locally retransmit damaged packets at a link layer. As a side effect of local retransmission, packet order of a flow may be altered.

[0034] Path Change: Over mobile ad-hoc networks, a TCP flow, for example, may traverse through a number of wireless nodes. A transmission path of a flow may be altered if one or more nodes move. A round trip time (RTT) of a connection may also change. Consequently, it may be possible that some packets transmitted after a path change arrive at a receiving end before one or more packets transmitted prior to path change.

[0035] Hand-Off: In infrastructure-based networks, a transmission coverage of an area may be achieved cooperatively by a set of base stations. If a mobile client moves from a radio range of one base station to that of another, a hand-off between these two base stations takes place. A transmission path for a flow may therefore be changed. Using a token, such as in the case of a path change, a resulting variation in RTT may lead to one or more occurrences of packet reordering.

[0036] Therefore, in wireless networks, packet reordering or random packet loss, in addition to packet losses due at least in part to network congestion (referred to herein as congestive packet loss), may result in out-of-order events. Due at least in part to conventional designs not being compliant with TCP, congestion control measures may be spuriously activated, keeping the congestion window (cwnd) unnecessarily small, thereby resulting in under-utilization of available network resources.

[0037] Problems of packet reordering or random packet loss have resulted in efforts to modify TCP to adapt it to wireless networks. Currently, these modified TCP variants fall into three different categories of packet reordering, random packet loss, or packet reordering and packet loss.

[0038] Prior approaches to packet reordering focused at least in part on detecting spurious retransmission after activating packet retransmission or congestion response. These approaches infer a path change upon a successful detection. Yet, as shown by simulation results, persistent packet reordering may interfere with performance.

[0039] By contrast, other prior approaches to packet reordering defer packet retransmission or congestion response until an occurrence of packet loss may be accurately confirmed. However, these variants may rely on link layer retransmission (LLRTX) to provide an almost error-free transmission channel and further may assume absence of random packet loss. After detection of a packet loss, congestion response, in addition to packet retransmission, may also be activated. Simulation results reveal, however, that these prior approaches may suffer performance deterioration if LLRTX is unavailable.

[0040] At least some prior approaches to random packet loss may focus on differentiating between congestion loss and non-congestion loss while not attending to packet reordering. This limitation restricts the prior approaches' applicability to networks with nearly in-order packet delivery. Particularly, their interoperability with LLRTX may be undermined.

[0041] Other prior approaches to packet reordering or random packet loss involve high deployment cost. For example, at least one prior approach introduces a layer between TCP and the internet protocol (IP). The introduced layer switches TCP among various pre-defined states in accordance with network conditions to address spurious packet retransmission or congestion response.

[0042] One or more embodiments described herein relate to end-to-end congestion control over wireless networks. For example, one or more embodiments may improve communication protocol performance in wireless networks by differentiating among network congestion, packet reordering, or random packet loss.

[0043] Although embodiments described herein refer to TCP, the scope of the various example embodiments are not limited to any particular protocol. Further, references to TCP herein refer to transfer protocols implemented in a manner compatible with or compliant with TCP.

[0044] For an example embodiment, a new retransmission decision timer RD; may be started if a new packet P_i is injected into the network. If the acknowledgment for P_i, ACK_i, is received at the TCP sender before RD_i expires, RD_i may be cancelled. Otherwise, after expiration of RD_i, P_i may be deemed as probably lost and retransmitted and a congestion response decision timer CD_i may be started. CD_i may be cancelled if ACK_i arrives before it expires. Otherwise, it would be further inferred that P_i is probably lost due to network overload. Congestion control mechanisms may be activated in response to expiration of CD_i. Expiration periods of RD_i and CD_i may be specified to be the maximum and the minimum values over a range of recently recorded RTT samples, respectively, for an example embodiment.

[0045] For the present example embodiment, a TCP non-congestive loss (NCL) RTT update process (TCP-NCL-RTT-Update) may be activated if ACK_i arrives before CD_i expires. To address ambiguity regarding whether the ACK_i is for the originally transmitted P_i or the retransmitted P_i, the process may, in an embodiment, compute an RTT sample for P_i if and only if ACK_i arrives no later than a prescribed time instance after RD_i expires.

[0046] Regarding activation of congestion control mechanisms, packet losses within a signal burst may be considered a single signal with respect to onset of network congestion and reduction of a congestion window may be triggered once. For one or more embodiments, evolution of a congestion window may follow slow start and congestion reduction processes as specified in RFC 2581. [Allman et al. "TCP Congestion Control," *Request for Comments*, RFC 2581, Network Working Group, Internet Engineering Task Force, April 1999] However, other embodiments may employ other approaches.

[0047] Example embodiments described herein may be referred to as TCP for Non-Congestive Loss (TCP-NCL). Of course, as previously mentioned, TCP is merely an example communication protocol, and other embodiments may be implemented based at least in part on other communication protocols. Further, embodiments described herein may employ variations to TCP, in one or more embodiments. Example embodiment TCP-NCL, as described herein, comprises an extension of sender-side TCP for improving performance of TCP over wireless networks by enabling TCP to differentiate among occurrences of network congestion, packet reordering, or random loss.

[0048] The following variables are used in describing an example embodiment, referred to as TCP-NCL. Other symbols are of local use exclusively within a particular section and will be defined in those sections.

[0049] ACK_i represents an acknowledgment packet for Packet P_i;

[0050] β comprises a system design parameter falling between zero and one;

[0051] CD_i represents a congestion response decision timer for packet P_i;

[0052] cwnd represents size of a congestion window;

[0053] maxRTT represents a maximum round-trip time (RTT) sample in storage;

[0054] minRTT represents a minimum RTT sample in storage;

[0055] P_i represents an i'th data packet transmitted by a TCP sender to a TCP receiver;

[0056] RD_i represents a retransmission decision timer for packet P_i;

[0057] RTT_i comprises the RTT for packet P_i;

[0058] ssthresh represents a slow start threshold value;

[0059] SMSS comprises a size of a largest packet that a sender can transmit;

[0060] t_{Pi} comprises a time instant at which a Packet P_i is injected into a network;

[0061] t_{ACKi} comprises a time instant at which an ACK_i arrives at a TCP sender, or if multiple ACK_i's arrive, a time instant a first ACK_i arrives;

[0062] T_{RDi} represents an expiration period of RD_i;

[0063] T_{CDi} represents an expiration period of CD_i;

[0064] In conventional TCP variants for dealing with persistent packet reordering, such as RR-TCP, TCP-DCR, and TCP-PR, packet retransmission or congestion response mechanisms are generally bundled together. A limitation may be that information inferred by occurrence of the events which happen after packet retransmission may be overlooked, thereby increasing a possibility of spurious congestion control activation. For example, if an acknowledgment for a packet lags behind a retransmission of that packet by a short duration, congestion control measures generally bundled with packet retransmission may be unnecessary. An acknowledgment packet may be for an originally transmitted packet or a retransmitted packet. The former case rejects possibility of a congestive loss. In the latter case, a fairly short round-trip time and thus a lightly loaded network may be inferred. Based at least in part on the observation noted above, packet retransmission and congestion control may be separated for one or more example embodiments described herein, such as for the following illustrative example.

[0065] FIG. **1** shows a flowchart depicting an example process embodiment **100**. RD_i may be started in response to P_i being injected into a network. If ACK_i is received by packet P_i sender before RD_i expires, RD_i may be cancelled. Otherwise, at least in part in response to expiration of RD_i, P_i may be retransmitted and CD_i may be started. CD_i may be cancelled if ACK_i arrives before CD_i expires. Otherwise, process embodiment **102** of activating congestion control mechanisms may be entered after expiration of CD_i and the size of cwnd may be halved. Therefore, installation of CD_i may allow a TCP sender extra time after packet retransmission to decide whether to activate congestion control. ACK_i arriving before expiration of CD_i may be interpreted as an indication little or no network congestion, and that activation of congestion control measures may be necessary.

[0066] A set of memory locations for recording or storing outstanding packets, outstanding-packet-list (herein referred to as opkt-list), may be defined and initialized to empty at the beginning of a TCP session. Packet P_i may be added to opkt-list in response to it being first transmitted and may be removed from the set if ACK_i arrives at or reaches a TCP sender. An opkt-list may be maintained for facilitating an operation of process embodiment **102**, as will be discussed later.

[0067] FIGS. **2***a*-**2***d* illustrate how for at least one embodiment decisions may be made on whether to activate packet retransmission or congestion control measures. FIG. **2***a* shows a situation in which ACK_1 arrives at a TCP sender before RD_1 expires. Neither packet retransmission nor congestion control measures are activated in this case, for an example embodiment.

[0068] FIGS. **2***b* and **2***c* show a situation in which ACK_1 arrives after RD_1 expires but before CD_1 expires. P_1 may be retransmitted after expiration of RD_1 but congestion control measures are not necessarily activated. FIG. **2***d* for this example embodiment illustrates that ACK_1 does not arrive before CD_1 expires. P_1 may be retransmitted after expiration of RD_1. Congestion control measures may be activated after expiration of CD_1.

[0069] It may be observed that TCP-NCL may be able to make decisions under three distinct situations depicted by FIGS. **2***a* through **2***d*. In other words, retransmission of packets may be triggered in the event of lost packets or congestion control measures may be triggered in the event of congestive loss. In the case of FIG. **2***b*, TCP-NCL may activate packet retransmission unnecessarily. Nevertheless, activation of congestion control may be substantially addressed.

[0070] FIG. **3** depicts a TCP-NCL-RTT-Update process embodiment **101** for maintaining storage of RTT samples, for example. Process **101** samples RTT of Packet P_i if ACK_i arrives before expiration of RD_i or between expiration of RD_i and CD_i. In the latter case, there is an ambiguity regarding whether the ACK_i corresponds to an originally transmitted packet or a retransmitted packet. Thus, measures may be employed so that ACK_i may be checked before recording a corresponding RTT sample. Time elapsed, for example, between retransmission of P_i and arrival of ACK_i may be measured for an example embodiment. If the measured value is less than β*minRTT, it may be inferred that the RTT sample be recorded accordingly. Otherwise, the corresponding RTT sample may be ignored. In other words, for an embodiment, RTT may be sampled for P_i as:

$$RTT_i = t_{ACKi} - t_{Pi} \tag{2.1}$$

where:

$$t_{ACKi} < t_{Pi} + T_{RDi} + \beta^{*}\text{minRTT} \tag{2.2}$$

[0071] By updating RTT based at least in part on acknowledgments received between expirations of RD_i and CD_i, robustness of RTT sampling process **101** to changes in a network environment may be increases, especially to occurrence of an abrupt increase in RTT, which may be incurred by path change or handoff. If there is an abrupt increase in RTT, ACK_i may not be received before RD_i expires. Yet, the corresponding RTT sample may still be accurately recorded if it does not exceed T_{RDi}+β*minRTT, for an example embodiment.

[0072] Distribution of RTT may be time-variant over most wireless networks, which in turn may result in periodic updating of RTT samples so that recent RTT samples are recorded and some outdated samples are discarded. Thus, a maximum RTT record length (herein referred to as MRRL) may be defined. In the event the total number of stored RTT samples exceeds MRRL, the oldest samples (meaning samples recorded at the earliest times) may be discarded, for one or more embodiments.

[0073] For an example embodiment, robust values for β and MRRL should be employed. β should be sufficiently small so that acknowledgments for retransmitted packets do not significantly affect RTT sampling. Yet, a too conservative β may undermine a robustness of TCP-NCL-RTT-Update for an abrupt increase in RTT. MRRL should be large enough to allow storage of a sufficiently large RTT sample, but should also be appropriately limited so that outdated samples may be discarded in time, for an embodiment. Nevertheless, simulation results reveal that performance may be robust over a wide range of combinations of values for β and MRRL ($0.5 \leqq \beta \leqq 0.95$, $200 \leqq \beta \leqq 1000$). For an example embodiment, recommended values for β and MRRL may comprise:

$$\beta = 0.8 \tag{2.3}$$

$$\text{MRRL} = 1000 \tag{2.4}$$

although this is merely an illustrative example and is not intended to limit claim scope.

[0074] FIGS. **4***a* through **4***c* illustrate RTT sampling for an embodiment, given, as an example, β=0.8 and minRTT=3. FIG. **4***a* shows that ACK_i may arrive at a TCP sender before RD_i expires. Relation (2.2) may be satisfied and corresponding RTT may be sampled according to relation (2.1).

[0075] FIG. **4***b* illustrates a situation in which ACK_i may arrive after RD_i expires but before CD_i expires. Relation (2.2) may be satisfied in this case and a corresponding RTT may be sampled according to relation (2.1). FIG. **4***c* also shows a situation in which ACK_i may arrive after RD_i expires but before CD_i expires. Yet, relation (2.2) may be violated in this case and thus the corresponding RTT sample may be ignored, in this example.

[0076] Based at least in part on RTT samples maintained by a TCP-NCL-RTT-Update process, T_{RDi} may be set as:

$$T_{RDi} = \text{maxRTT} \tag{2.5}$$

although this is merely an illustrative example and is not intended to limit claim scope.

[0077] An assignment of T_{RDi}; that reflects Packet P_i may be lost with high probability after expiration of RD_i. Thus, spurious packet retransmission may be reduced. However, excessively delaying packet retransmission should generally not be an issue as well.

[0078] For an example embodiment, CD timers operate so that an ACK_1 arriving before expiration of CD_i should reject occurrence of congestive loss to P_i. T_{CDi} should be no greater than a certain upper bound value, which is denoted as T_u. T_u is lower bounded by a minimum attainable RTT for P_i. Therefore, an improved solution for T_{CDi} within $[0, T_u]$ may be determined. Consider a time period t ($0 \leqq t \leqq T_u$) after retransmission of packet P_i, if a TCP sender may or may not activate a congestion response. Risk associated with a positive decision may be that the network may not be congested (e.g., the originally transmitted P_i may not be dropped). Consequently, a spuriously activated congestion response may reduce a congestion window unnecessarily. However, if the network is indeed overloaded (e.g., the originally transmitted P_i may be lost) and activation of congestion response is excessively delayed, network congestion may be exacerbated and an expensive retransmission timeout (RTO) may be incurred.

[0079] To quantify risk associated with activating a congestion response, a metric may be introduced, in an embodiment. An expected cost of activating a congestion response, $EC_A(t)$, may be defined as:

$$EC_A(t) = P(\overline{CL_i^o} | PU_i(t)) \cdot C_S \tag{2.6}$$

where $\overline{CL_i^o}$ denotes the event of originally transmitted P_i not being lost, $PU_i(t)$ denotes the event P_i is unacknowledged by time t after retransmission of P_i, $P(\overline{CL_i^o}|PU_i(t))$ denotes the conditional probability of $\overline{CL_i^o}$, given $PU_i(t)$, and C_S denotes the throughput reduction attributable to activation of a congestion response.

[0080] Similarly, expected cost of delaying a congestion response, $EC_D(t)$, may be introduced to quantify risk associated with delaying congestion response. It may be defined for an embodiment as:

$$EC_D(t) = P(CL_i^o \cap RTO | PU_i(t)) \cdot C_T \tag{2.7}$$

where CL_i^o denotes the event of originally transmitted P_i not being lost, $P(CL_i^o \cap RTO | PU_i(t))$ denotes the conditional probability of CL_i^o and RTO occurring, given $PU_i(t)$, and C_T denotes throughput reduction.

[0081] For $0 \leqq t \leqq T_u$, $EC_A(t)$ and $EC_D(t)$ may be derived as:

$$EC_A(t) = \frac{p_w[1-(1-p_l)F(t)]}{p_c + p_w[1-(1-p_l)F(t)]}C_S \tag{2.8}$$

$$EC_D(t) = \frac{p_w p_l}{p_c + p_w[1-(1-p_l)F(t)]}C_T \tag{2.9}$$

where p_c denotes the congestive loss rate, p_w denotes non-congestive loss rate, and p_l denotes total loss rate.

[0082] C_S and C_T may be computed as:

$$C_S=0.5(W-\lceil 0.5W \rceil)(W-\lceil 0.5W \rceil+1) \tag{2.10}$$

$$C_T=0.5(\lceil \log_2 0.5W \rceil W-2^{\lceil log2 0.5W \rceil}+1) \tag{2.11}$$

$EC_A(t)$ monotonically decreases and $EC_D(t)$ monotonically increases with t. Thus, if the activation of congestion response is postponed further, $EC_D(t)$, which quantifies risk associated with delaying a congestion response, increases, while $EC_A(t)$, which quantifies risk associated with activating a congestion response, drops. If $EC_A(t)$ is greater than $EC_D(t)$, it is advantageous to set T_{CDi} no less than t since the operational cost of triggering a congestion response comprises $EC_A(t)$, which is larger than that of deferring it, $EC_D(t)$. Cost may drop as t further increases. Similarly, if $EC_D(t)$ is greater than $EC_A(t)$, it is advantageous to set T_{CDi} no greater than t since the operational cost of deferring a congestion response comprises $EC_D(t)$, which is larger than that of triggering it, $EC_A(t)$. Cost may drop as t decreases. Therefore, for an embodiment, a solution for T_{CDi}, T_{CDi}*, corresponds to $EC_A(T_{CDi})$ just outweighing $EC_D(T_{CDi})$ subject to the constraint $0 \leqq t \leqq T_u$, for an example embodiment.

[0083] Evaluation of T_{CDi}* may be divided into three cases. A first arises if $EC_D(t)$ exceeds $EC_A(t)$ for any $t \geqq 0$. A gap between the two would continue to increase as t increases. Thus, a congestion response may be activated at t=0, or set T_{CDi}* to be zero. A second case arises if $EC_D(t)$ fails to catch up with $EC_A(t)$ for all t such that $0 \leqq t \leqq T_u$. Assuming that we may not delay a congestion response further than T_u according to a prior constraint, we may set T_{CDi}* to be T_u. A final case arises if $EC_D(t)$ catches up with $EC_A(t)$ for some t such that $0 \leqq t = T_{TH} \leqq T_u$ As stated above, T_{CDi}* corresponds to T_{TH}.

[0084] Thus, for an example embodiment, T_{CDi}* may be given by:

$$\tau^*_{CD_i} - \begin{cases} 0, & p_c > \dfrac{p_l C_S}{p_l C_T + C_S} \\ \tau_u, & p_c < \dfrac{p_l C_S}{\dfrac{p_l}{1-(1-p_l)F(\tau_u)}C_T + C_S} \\ \tau_{TH}, & \text{otherwise} \end{cases} \tag{2.12}$$

-continued

where

$$\tau_{TH} = F^{-1}\left(\frac{1-\dfrac{C_T p_c}{C_S p_w}}{1-p_l}\right).$$

[0085] It may be shown that

$$p_c \leqq \frac{p_l C_S}{p_l C_T + C_S}$$

when $p_c \leqq p_c \ll 1$. Thus, it is reasonable to assume T_{CDi}* be T_{TH} or T_u, depending at least in part on the value of p_c. A conservative estimation for both T_{TH} and T_u may be set as a minimum attainable RTT for P_i, in an embodiment. Hence, as an approximation, we may set

$$T_{CDi}=\text{minRTT} \tag{2.13}$$

[0086] For activation of congestion control measures process embodiment **102**, we may adopt an approach similar to the one used in TCP-PR that packet losses within the same burst may be considered as a single signal about onset of network congestion and reduction of cwnd may be triggered once, therefore.

[0087] FIG. **5** shows process embodiment **102** of activating congestion control measures. A set of memory locations for recording packets, exempted-packet-list (epkt-list), may be defined and initialized to empty at the beginning of a TCP session. At least in part in response to entering process embodiment **102** of activating congestion control measures, if an outstanding packet P_i is not in the epkt-list, cwnd and ssthresh may be set to half of the present cwnd, and the whole current opkt-list may be added to epkt-list. Otherwise, cwnd and ssthresh may be left intact since a probable congestive loss of P_i may have already been responded to by an earlier reduction of cwnd for loss of previous packets within the same burst.

[0088] Evolution of cwnd for this example embodiment follows slow start or congestion avoidance as specified in RFC 2581, mentioned above, which may briefly be reiterated as follows.

[0089] An initial value of cwnd, IW, may satisfy:

$$IW \leqq 2*SMSS \tag{3.1}$$

[0090] An initial value of ssthresh may be arbitrarily high. A slow start process may be used if

$$\text{cwnd} \leqq \text{ssthresh} \tag{3.2}$$

while a congestion avoidance process may be used if

$$\text{cwnd} > \text{ssthresh}. \tag{3.3}$$

[0091] During slow start, cwnd may be incremented by SMSS bytes for an acknowledgment packet received that acknowledges additional signals. Slow start may end if cwnd exceeds ssthresh or if congestion is detected.

[0092] During a congestion avoidance process, cwnd may be incremented by SMSS bytes per RTT. As an example, a process may continue until congestion is detected, for an embodiment.

[0093] In an embodiment, a retransmission timeout (RTO) may be implemented in a manner compatible with a transmission control protocol (J. Postel. "Transmission Control

Protocol", RFC 793). RTO may be modified in an TCP-NCL embodiment so that it may occur in a controllable manner. An expiration period of a RTO timer, T_{RTO}, may be set to:

$$T_{RTO}=\text{backoff}*(T_{RDi}+2*T_{CDi;});$$

[0094] An RTO timer may reset after packet transmissions and retransmissions, in an embodiment. backoff may be set to "one" initially and may be reset to "one" after an acknowledgement of additional signal packets. After an occurrence of RTO, a size of a congestion window may be reduced to "one" and backoff may be doubled if it is no greater than 64. A determination may be made as to whether there are retransmitted packets that are not acknowledged within an expiration period of an RD timer, or whether a congestion window is no greater than one. If either is true, all or approximately all outstanding packets may be retransmitted at a rate regulated by a congestion window.

[0095] Below, performance of an embodiment example for TCP-NCL is compared with those of conventional TCP variants via simulation using Network Simulator (ns) Version 2.29 [Fall et al. "The ns manual (formerly ns Notes and Documentation)", The VINT Project, January 2009.].

[0096] FIGS. **6***a* through **6***d* illustrate four different network topologies used in a simulation experiment: an example wired network with a dumbbell topology **601**, an example infrastructure-based wireless network **602**, an example multi-hop wireless network **603**, and an example wired network with a bottleneck link of time-varying propagation delay **604**. Performance of TCP-variants under congestive loss, random packet loss, persistent reordering, and occurrences of abrupt increase in RTT are to be examined.

[0097] FIG. **6***a* illustrates example wired network with a dumbbell topology **601**. Multiple pairs of TCP-NCL senders **605** and receivers **606** share an error-free ordered bottleneck link **607**. Thus, occurrences of packet loss here are due to network congestion. The number of sender-receiver pairs ranges here from one to ten.

[0098] FIG. **6***b* illustrates example infrastructure-based wireless network **602**. A TCP sender **608** and a TCP receiver **609** are connected through a wired link **610** and a wireless link **611**. Random channel error from zero to 15% is deliberately introduced into wireless link **611**. A link-layer retransmission mechanism is disabled to simulate an in-order error-prone channel for a TCP flow.

[0099] FIG. **6***c* illustrates example multi-hop wireless network **603**. A TCP sender **612** is connected to a TCP receiver **613** via four wireless links **614**, **615**, **616**, **617**. Random channel error is introduced into wireless links **614**, **615**, **616**, **617** with an error rate ranging from zero to 15%. Link-layer retransmission is enabled to introduce persistent packet reordering. Under high channel error rate, however, local link-layer retransmission cannot guarantee successful packet delivery due to a retransmission limit (set to three). Consequently, TCP may be confronted with both packet reordering and random packet loss.

[0100] FIG. **6***d* illustrates the wired network with a bottleneck link of time-varying propagation delay **604**. A TCP connection traverses through a bottleneck link **618**. A link delay of a bottleneck link takes on a random value from an interval [50, maxDy] ms and is changed at 20 second intervals. maxDy ranges from 100 ms to 700 ms. This way, an RTT may experience abrupt variations (and thus abrupt increases in some cases)

[0101] Simulation results are shown in FIG. **7**, FIG. **8**, FIG. **9**, and FIG. **10**. In the dumbbell topology **601**, there are a number of TCP-NCL flows sharing bottleneck link **606**. A normalized throughput of TCP flow, which is defined as a ratio of throughput to average throughput among the flows, is computed. FIG. **7** shows normalized throughputs plotted against number of TCP flows **700**. Plotted normalized throughputs **700** are approximately one unit. FIG. **8** shows total throughput of TCP flows plotted against number of TCP flows **800**, which may be observed to maintain at a high level despite an increase in number of flows. Thus, TCP-NCL flows are able to share bandwidth of a bottleneck link fairly and efficiently, demonstrating competent responsiveness in the presence of congestive loss only.

[0102] FIG. **9** shows connection throughput performance curves **900** of TCP variants over the infrastructure-based wireless network. In each test, a total of 20 runs have been performed to compute an average value and a 95% confidence interval of a connection throughput in megabit per second (Mbps). For TCP-NCL, MRRL is set to 1000 and β is set to 0.8. TCP-NCL **904** essentially maintains a stable throughput level against channel error rate from zero to 15%, whereas other TCP variants experience throughput decrease as error rate increases. An exception is TCP-W **907**, which exhibits a relatively elegant performance deterioration. Performance of TCP-NCL **904** may be attributable to its effectiveness in differentiating between congestion loss and random packet loss, a merit introduced by postponing activation of congestion response until a congestion response decision timer expires. In contrast, RR-TCP **901**, TCP-DCR **902**, TCP-DOOR **903**, and TCP-PR **905** exclude the possibility of random packet loss, resulting in under-utilization of network resources.

[0103] FIG. **10** shows connection throughput performance curves **1000** of TCP variants over multi-hop wireless network **603**. In a test, a total of 20 runs have been performed to compute an average value and a 95% confidence interval of a connection throughput in megabit per second (Mbps). TCP-DCR **1002**, TCP-NCL **1004**, and TCP-PR **1005** outperform other variants for channel error rate less than 9%, thereby demonstrating robustness to persistent reordering. If the error rate further increases and random packet loss coexists with packet reordering, TCP-NCL **1004** performs slightly better than TCP-PR **1005** while performance of TCP-DCR **1002** is deteriorated. Again, in the latter scenario, installation of a congestion response decision timer plays a role in achieving performance improvement for TCP-NCL **1004**.

[0104] FIG. **11** shows connection throughput performance curves **1100** of TCP variants over the wired network topology **604** simulating occurrences of abrupt increases in RTT. In a test, a total of 20 runs have been performed to compute an average value and a 95% confidence interval of connection throughput in megabit per second (Mbps). Among possible solutions for packet reordering (RR-TCP **1101**, TCP-DCR **1102**, TCP-DOOR **1103**, TCP-NCL **1104**, TCP-PR **1105**), TCP-DCR **1102** produces second worst performance gain attributable to its inability of maintaining accurate RTT sampling with the presence of abrupt RTT variations. If RTT abruptly increases, TCP-DCR tends to prematurely fire its fast retransmission timer and spuriously trigger packet retransmission. The RTT sample for the spuriously retransmitted packet and thus the increase in RTT is subsequently ignored, leading to further spurious packet retransmission. By contrast, RR-TCP **1101**, TCP-NCL **1104**, and TCP-PR

1105 offer improved connection throughput. Thus, a TCP-NCL-RTT-Update process **101** may be partially verified as a robust RTT sampling mechanism for occurrences of abrupt increases in RTT.

[0105] FIG. **12** shows connection throughput performance curves **1200** of TCP variants over a mobile ad-hoc network. A total of 16 mobile nodes are confined to an area of 1000 m×1000 m with initial positions uniformly distributed. Signal rate of a wireless interface is 2 Mbps. IEEE 802.11 serves as the MAC layer protocol with a transmission range of 250 m and a sensing range of 550 m. A TCP flow is set up between two selected nodes with DSR as an underlying routing process. The movement pattern follows the random waypoint model with a maximum speed set to maxSpeed and a maximum pausing time set to ten seconds. maxSpeed ranges from 5 m/s to 50 m/s. Thus, packet reordering may be incurred if path change leads to variations in RTT, while burst loss from temporary disconnection may result from node movement. A total of 80 runs, each lasting 2000 seconds and using different seeds for generating node movements, have been done for a test to compute an average value and a 95% confidence interval of TCP throughput in Mbps. To remove an effect of the transient states, statistics in the last 1000 seconds of run are collected for computing throughput. The TCP variants offer deteriorated throughput performance (below 15% of the interface rate), which may be attributable to occurrences of non-congestive burst loss from disconnections. In theory, it is possible for TCP-NCL to differentiate non-congestive burst loss from congestive loss, given that a corresponding disconnection event produces loss of originally transmitted packets within a window and may be recovered prior to the retransmission of these packets. During that event, retransmitted packets may be acknowledged in time so that a congestion response may not be falsely activated. This may explain why TCP-NCL **1204** generally appears to offer better performance than other variants under study (**1201**, **1202**, **1203**, **1205**, **1206**, and **1207**).

[0106] FIG. **13** is a schematic diagram illustrating an example computing or communications environment **1300** that may include one or more devices capable of implementing techniques or processes described above, for example, in connection with example techniques discussed above or depicted in FIGS. **1-12**. System **1300** may include, for example, a first device **1302**, a second device **1304**, and a third device **1306**, which may be operatively coupled together through a wireless communication network **1308**.

[0107] First device **1302**, second device **1304** and third device **1306**, as shown in FIG. **13**, may be representative of any device, appliance or machine that may be capable of exchanging signals over wireless communications network **1308**. By way of example but not limitation, any of first device **1302**, second device **1304**, or third device **1306** may include: one or more computing devices or platforms, such as, e.g., a desktop computer, a laptop computer, a workstation, a server device, or the like; one or more personal computing or communication devices or appliances, such as, e.g., a personal digital assistant, mobile communication device, or the like; a computing system or associated service provider capability, such as, e.g., a database or storage service provider/system, a network service provider/system, an Internet or intranet service provider/system, a portal or search engine service provider/system, a wireless communication service provider/system; or any combination thereof. Any of the first, second, and third devices **1302**, **1304**, or **1306**, respectively, may comprise one or more of an almanac server, an access point, or a mobile station in accordance with examples described herein.

[0108] Similarly, network **1308**, as shown in FIG. **13**, is representative of one or more communication links, processes, or resources capable of supporting exchange of signals between at least two of first device **1302**, second device **1304**, and third device **1306**. By way of example but not limitation, network **1308** may include wireless or wired communication links, telephone or telecommunications systems, signal buses or channels, optical fibers, terrestrial or space vehicle resources, local area networks, wide area networks, intranets, the Internet, routers or switches, and the like, or any combination thereof. As illustrated, for example, by the dashed lined box illustrated as being partially obscured of third device **1306**, there may be additional like devices operatively coupled to network **1308**.

[0109] It is recognized that all or part of the various devices and networks shown in system **1300**, and the processes and methods as further described herein, may be implemented using or otherwise including hardware, firmware, software, or any combination thereof.

[0110] Thus, by way of example but not limitation, second device **1304** may include at least one processing unit **1320** that is operatively coupled to a memory **1322** through a bus **1328**.

[0111] Processing unit **1320** is representative of one or more circuits capable of performing at least a portion of a signal processing procedure or process. By way of example but not limitation, processing unit **1320** may include one or more processors, controllers, microprocessors, microcontrollers, application specific integrated circuits, digital signal processors, programmable logic devices, field programmable gate arrays, and the like, or any combination thereof.

[0112] Memory **1322** is representative of any signal storage mechanism. Memory **1322** may include, for example, a primary memory **1324** or a secondary memory **1326**. Primary memory **1324** may include, for example, a random access memory, read only memory, etc. While illustrated in this example as being separate from processing unit **1320**, it should be understood that all or part of primary memory **1324** may be provided within or otherwise co-located/coupled with processing unit **1320**.

[0113] Secondary memory **1326** may include, for example, the same or similar type of memory as primary memory or one or more signal storage devices or systems, such as, for example, a disk drive, an optical disc drive, a tape drive, a solid state memory drive, etc. In certain implementations, secondary memory **1326** may be operatively receptive of, or otherwise capable of coupling to, a computer-readable medium **1340**. Computer-readable medium **1340** may include, for example, any medium that is able to carry or make accessible signal information, code or instructions for one or more of the devices in system **1300**. Computer readable medium **1340** may also be referred to as a storage medium.

[0114] Second device **1304** may include, for example, a communication interface **1330** that may provide for or otherwise support operative coupling of second device **1304** to at least network **1308**. By way of example but not limitation, communication interface **1330** may include a network interface device or card, a modem, a router, a switch, a transceiver, and the like.

[0115] Second device **1304** may include, for example, an input/output **1332**. Input/output **1332** is representative of one or more devices or features that may be configurable to accept or otherwise introduce human or machine inputs, or one or more devices or features that may be configurable to deliver or otherwise provide for human or machine outputs. By way of example but not limitation, input/output device **1332** may include an operatively configured display, speaker, keyboard, mouse, trackball, touch screen, data port, etc.

[0116] Methodologies described herein may be implemented by various approaches depending at least in part upon applications according to particular examples. For example, such methodologies may be implemented in hardware, firmware, software, or combinations thereof. In a hardware implementation, for example, a processing unit may be implemented within one or more application specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), processors, controllers, micro-controllers, microprocessors, electronic devices, other devices units designed to perform functions described herein, or combinations thereof.

[0117] "Instructions" as referred to herein relate to expressions which represent one or more logical operations. For example, instructions may be "machine-readable" by being interpretable by a machine for executing one or more operations on one or more objects. However, this is merely an example of instructions and claimed subject matter is not limited in this respect. In another example, instructions as referred to herein may relate to encoded commands which are executable by a processing circuit having a command set which includes encoded commands. An instruction may be encoded in the form of a machine language understood by a processing circuit. Again, these are merely examples of an instruction and claimed subject matter is not limited in this respect.

[0118] "Storage medium" as referred to herein relates to media capable of maintaining expressions which are perceivable or processable by one or more machines. For example, a storage medium may comprise one or more storage devices for storing machine-readable instructions or information. Storage devices may comprise any one of several media types including, for example, magnetic, optical or semiconductor storage media. Storage devices may also comprise any type of long term, short term, volatile or non-volatile memory devices. However, these are merely examples of a storage medium, and claimed subject matter is not limited in these respects.

[0119] Some portions of the detailed description included herein are presented in terms of algorithms or symbolic representations of operations on binary digital signals stored within a memory of a specific apparatus or special purpose computing device or platform. In the context of this particular specification, the term specific apparatus or the like includes a general purpose computer once it is programmed to perform particular operations pursuant to instructions from program software. Algorithmic descriptions or symbolic representations are examples of techniques used by those of ordinary skill in the signal processing or related arts to convey the substance of their work to others skilled in the art. An algorithm is here, and generally, is considered to be a self-consistent sequence of operations or similar signal processing leading to a desired result. In this context, operations or processing involve physical manipulation of physical quantities. Typically, although not necessarily, such quantities may take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared or otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to such signals as bits, data, values, elements, symbols, characters, terms, numbers, numerals, or the like. It should be understood, however, that all of these or similar terms are to be associated with appropriate physical quantities and are merely convenient labels. Unless specifically stated otherwise, as apparent from the discussion herein, it is appreciated that throughout this specification discussions utilizing terms such as "processing," "computing," "calculating," "determining" or the like refer to actions or processes of a specific apparatus, such as a special purpose computer or a similar special purpose electronic computing device. In the context of this specification, therefore, a special purpose computer or a similar special purpose electronic computing device is capable of manipulating or transforming signals, typically represented as physical electronic or magnetic quantities within memories, registers, or other information storage devices, transmission devices, or display devices of the special purpose computer or similar special purpose electronic computing device.

[0120] The terms, "and," and "or" as used herein may include a variety of meanings that will depend at least in part upon the context in which it is used. Typically, "or" if used to associate a list, such as A, B or C, is intended to mean A, B, and C, here used in the inclusive sense, as well as A, B or C, here used in the exclusive sense. Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of claimed subject matter. Thus, the appearances of the phrase "in one embodiment" or "an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in one or more embodiments.

[0121] While there has been illustrated and described what are presently considered to be example features, it will be understood by those skilled in the art that various other modifications may be made, or equivalents may be substituted, without departing from claimed subject matter. Additionally, many modifications may be made to adapt a particular situation without departing from claimed subject matter. Therefore, it is intended that claimed subject matter not be limited to the particular examples disclosed, but that such claimed subject matter may also include all aspects falling within the scope of the appended claims, or equivalents thereof.

1. A method for differentiating among congestive packet loss, packet reordering, or random packet loss comprising:

managing multiple timers at least in part in response to transmitting a signal packet, wherein said timers are set to start or expire at different time instances; and

activating one or more signal transmission control functions after expiration of one or more of said timers, wherein said one or more signal transmission control functions comprise congestion control measures or loss recovery measures.

2. The method of claim **1**, wherein the expiration periods of said timers are determined as functions of overall packet loss rate, congestive packet loss rate, or size of congestion window.

3. The method of claim **1**, wherein said managing and said activating are compatible with a transmission control protocol (TCP).

4. A method for differentiating congestive packet loss, packet reordering, or random packet loss comprising:

starting a retransmission decision timer at least in part in response to injecting a signal packet into a network;

retransmitting the signal packet and starting a congestion control decision timer at least in part in response to an expiration of said retransmission decision timer, if an acknowledgment packet for the signal packet has not arrived; and

designating the signal packet to be lost at least in part in response to an expiration of the said congestion response decision timer, if an acknowledgment packet for the signal packet has not arrived.

5. The method of claim **4**, wherein the expiration periods of said retransmission decision timers or said congestion response decision timers are determined as functions of overall packet loss rate, congestive packet loss rate, or size of congestion window.

6. The method of claim **4**, wherein said starting, retransmitting, or designating are compatible with a transmission control protocol (TCP).

7. A method for differentiating congestive packet loss, packet reordering, or random packet loss comprising:

maintaining in storage a plurality of values of recent RTT samples;

starting a retransmission decision timer at least in part in response to injecting a signal packet into a network, wherein the expiration period of said retransmission decision timer is set to a maximum value among RTT samples in storage;

retransmitting the signal packet and starting a congestion control decision timer at least in part in response to the expiration of said retransmission decision timer if an acknowledgment packet for the signal packet has not arrived, wherein the expiration period of said congestion response decision timer is set to be a minimum value among RTT samples in storage; and

designating the signal packet to be lost after the expiration of said congestion response decision timer, if an acknowledgment packet for the signal packet has not arrived.

8. The method of claim **7**, wherein the said maintenance of RTT samples comprises:

discarding RTT samples that have been in storage for the longest duration if the number of RTT samples exceeds the maximum RTT record length, wherein the maximum RTT record length comprises a selected positive integer signal value;

calculating a time delay upper bound by multiplying a minimum value among stored RTT samples by a scalar signal value, wherein said scalar signal value is selected to be greater than zero and less than one; and

performing RTT sampling and adding an RTT sample into RTT storage at least in part in response to arrival of an acknowledgment packet if an acknowledgment packet arrives before said retransmission decision timer expires or no later than said time delay upper bound after said retransmission decision timer expires.

9. The method of claim **7**, wherein said starting, retransmitting, and designating are compatible with a transmission control protocol (TCP).

10. A method for differentiating among congestive packet loss, packet reordering, or random packet loss comprising:

maintaining in storage a plurality of values of recent RTT samples;

starting a retransmission decision timer at least in part in response to injecting a signal packet into a network, wherein an expiration period of said retransmission decision timer is set to a maximum value among RTT samples in storage;

retransmitting the signal packet and starting a congestion control decision timer at least in part in response to expiration of said retransmission decision timer if an acknowledgment packet for the signal packet has not arrived, wherein the expiration period of said congestion response decision timer is set to be a minimum value among RTT samples in storage; and

designating the signal packet to be lost after expiration of said congestion response decision timer, if an acknowledgment packet for the signal packet has not arrived;

starting a retransmission timer after transmitting a packet, a retransmission timer is not yet started, and resetting said retransmission timer if it is already started, wherein the expiration period of said retransmission timer is set to be the sum of the expiration period of said retransmission decision timer and twice the expiration period of said congestion decision timer;

designating a network to be congested and signal packets in transit to be lost upon the expiration of the said retransmission timer, if any retransmitted packet is not acknowledged within the expiration period of the retransmission decision timer, or the size of congestion window is less than one.

11. The method of claim **10**, wherein said maintenance of RTT samples comprises:

discarding RTT samples that have been in storage for a longest duration if the number of RTT samples exceeds a maximum RTT record length, wherein said maximum RTT record length comprises a selected positive integer;

calculating a time delay upper bound by multiplying a minimum value among stored RTT samples by a scalar signal value, wherein said scalar signal value is selected to be greater than zero and less than one; and

performing RTT sampling and adding a RTT sample into RTT storage at least in part in response to arrival of an acknowledgment packet if the acknowledgment packet arrives before said retransmission decision timer expires or no later than said time delay upper bound after said retransmission decision timer expires.

12. The method of claim **10**, comprising a congestion management process compatible with a transmission control protocol (TCP).

13. An apparatus, comprising:

means for managing multiple timers at least in part in response to transmitting a signal packet, wherein said timers are set to start or expire at different time instances; and

means for activating one or more signal transmission control functions after expiration of one or more of said timers, wherein said one or more signal transmission control functions comprise congestion control measures or loss recovery measures.

14. The apparatus of claim **13**, wherein expiration periods of said timers are to be determined as functions of overall packet loss rate, congestive packet loss rate, or size of congestion window.

15. The apparatus of claim **13**, wherein said means for managing and said means for activating operate in a manner compatible with a transmission control protocol (TCP).

16. The apparatus of claim **13**, wherein the apparatus comprises one or more of a programmable logic device (PLD), a field programmable gate array (FPGA), or an application-specific integrated circuit (ASIC).

17. An article, comprising: a storage medium having stored thereon instructions executable by a computing platform to:

manage multiple timers at least in part in response to transmitting a signal packet, wherein said timers are set to start or expire at different time instances; and

activate one or more signal transmission control functions upon expiration of one or more of said timers, wherein said one or more signal transmission control functions comprise congestion control measures or loss recovery measures.

18. The article of claim **17**, wherein expiration periods of the said timers are determined at least in part as functions of overall packet loss rate, congestive packet loss rate, or size of congestion window.

19. The article of claim **17**, wherein the storage medium has stored thereon further instructions executable by a computing platform to manage said multiple timers and said activating said one or more data transmission control functions in a manner compatible with a transmission control protocol (TCP).

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