Abstract

Rate Control plays an key role for many multimedia services such as streaming applications. These streaming applications such as video on demand (VoD) or voice over IP (VoIP) services face some critical problems such as insufficient bandwidth and improper performance of transmission protocols. Emerging real-time multimedia services over IP grow fast with the advent of advanced broadband communications and innovated interconnection technologies. Besides, the new generation networks are expected to integrate all heterogeneous wired and wireless networks and offer seamless customized multimedia services anywhere, anytime. However, wireless networks usually with low and variable bandwidth, and non-congestion related loss do bring the challenge to the existing transport protocol, such as TCP, TFRC etc. In this paper we propose a rate control scheme named Jitter-based Rate Control (JRC) to fit wired-wireless hybrid network which has better performance than the current rate control scheme.

1. Introduction

In recent years, the wireless mobile devices have been widely used for communication, commerce, education, entertainment and business works. According to popularity of these applications, the difference of Internet Protocol performances between wired link and wireless link are widely studied. In those areas which wireless mobile devices are used we mentioned above, real-time services and multimedia services plays important roles for killer-applications.

Rate Control is an important issue in many multimedia services such as streaming applications. These applications use User Datagram Protocol (UDP) or Real-time Transport Protocol (RTP) for their transmission protocol rather than TCP because they need not re-transmission and error resilience catarrhines. However, these protocols do not have a congestion control mechanism. If we use these protocols without any congestion control mechanisms for their rate control, other traffics use TCP will have bad performance due to drop-to-zero problems. These streaming applications such as video on demand (VoD) or voice over IP (VoIP) services face some critical problems such as low bandwidth and bad performance of transmission protocols. These real-time multimedia traffics grow with increasing of link bandwidth and data transmission speed in current Internet. Many kinds of mobile devices such as PDAs or cell phones also contain real-time multimedia applications. These services are widely provided in recent years and revolute human being's behavior in communications.

Wireless networks were known as low bandwidth and non-congestion related loss. As the wireless transmission technology advances, the transmission capability (e.g. bandwidth) may increase but non-congestion related loss remains a critical issue. In other words, a intelligent way to distinguish wireless random loss from Internet congestion loss is required for the new generation broadband IP Networks. The most popular rate-control protocol which published these years was TCP-friendly rate control[6], a equation-based rate control scheme. A traffic applying TFRC makes its transmission rate close to TCP flows, which is the dominating traffic on Internet so TFRC can avoid TCP drop-to-zero problem.

However, TFRC is proposed for wired networks. Problems which wireless TCP[4][7][8] studies also happen on TFRC over wireless networks due to characteristics of wireless environment. Wireless traffics face random-loss problems for variation of wireless network environment. These loss events count as congestion losses in TCP or TFRC, and then sender of this traffic may decreases its transmission rate for congestion-avoidance. This problem will happen frequently in current wireless networks (e.g. IEEE 802.11 WLAN) or beyond 3G environments (e.g. IEEE 802.16 WMAN)[20][21][22]. In Wireless MAN
environment the wireless links may locate in the second hop or last mile of traffic paths. If a rate control algorithm or congestion control algorithm can not work in any topology of wired-wireless hybrid network than it will not be a useful solution.

In this paper we proposed a rate control scheme named Jitter-based Rate Control (JRC) and it works no matter where wireless link locates in a wired-wireless hybrid network. JRC can be used for best-effort network and performance better than current rate control mechanisms.

2. Related Work

First, we introduce available bandwidth analysis mechanism and end-to-end congestion detection and available bandwidth issue. Then, the most popular rate-control scheme known as TFRC will be introduced. In additional, we introduce some modified-TFRC schemes which are proposed to solve wireless random-loss problem. Finally, 802.16 network will be introduced and we will explain why those solutions we described can not work in such network topologies.

2.1. End-to-end statistics to detect congestion

The goal of Wireless TCP research is to improve TCP performance on wireless link. One of the most important characteristics of wireless data transmission is wireless random loss problem. This problem which is also known as random loss or wireless loss problem does to variation of wireless network environment. This is the most different data transmission issue on wired and wireless network. When packet loss event happens in wired network it is treated as congestion loss and sender reduce it's sending rate. But packet loss event happens in wireless network or wired-wireless hybrid network might be treated as congestion loss or wireless random loss. If the loss event due to congestion loss sender most reduce it's sending rate for too many data flows were transmitted on net. On the other hand, loss event due to wireless random loss does not denote a bad network condition. Misjudging of loss event will decrease transmission performance of the connection.

The main issue of wireless TCP is how to distinguish packet loss events due to congestion or wireless link random loss. [7][8][9] uses round trip time(RTT) to differ wireless random losses from congestion losses. [4] uses inter-arrival jitter to differ wireless loss. Figure.1 shows how inter-arrival jitter happens.

Some other loss differentiation algorithms (LDAs) using relative one-way trip time(ROTT) than using RTT. ROTT analyze relationship between current one-way trip time with minima one-way trip time. This relationship shows current network condition variation. [3][12][23] are these LDAs who use ROTT.

2.2. TFRC

There are two rate-control schemes on study in recent years: window-based and equation-based rate control scheme. As the name suggests, window-based rate control scheme such as TCP controls it's sending rate by increase/decrease congestion window size. Equation-based rate control scheme uses equations to calculate it's transmission rate. TCP Friendly Rate Control (TFRC)[6] is an end-to-end rate control mechanism for unicast traffic. It is a equation-based rate control scheme and its data transmission rate is close to TCP. That's why it calls "Friendly". TFRC is usually used in UDP and RTP for their congestion control mechanism.

2.3. Modified TFRC

However, TFRC faces the same problem in wireless links with TCP -- the misjudge of wireless loss to congestion loss. Modified TFRC schemes which are proposed for treating wireless environment characteristics still contain those issues Wireless TCP studies. Rate control schemes in streaming applications over wireless network are differed into two parts: TFRC-aware snoop-like model solutions and end-to-end solutions. The advantage of snoop-like model solutions is easily to do a local retransmission by catching packets on some network elements. The disadvantage is that it requires modifications to the network infrastructure. TFRC-aware snoop-like models such as [24] needs special network elements. Most of these kind of elements are base stations which contain special functions. The most impairment work these elements do is to avoid wireless network effects the connection. So it can retransmit buffered packets in
base station when client user requests retransmission, or do priority queues for important data packets.

However snoop-like model solutions need to modify network infrastructure. It makes snoop-like model solutions cost high and hard to implement. End-to-end solutions such as [1][2][5] need not to change network infrastructure, but they must solve wireless problems by using limited parameters such as packet loss rate or timestamps. The most important work of these solutions do is reducing the wireless packet random loss effect.

[1] models TCP behavior to calculate a current sending rate and avoids wireless channel effect. The authors first establish end-to-end path model by four-state Markov chain which constructs the physical layer abstract on wired-wireless hybrid link. They combine this path model with their TCP behavior model as Figure.2. ARC delivers wireless packet loss rate from total packet loss rate and uses these parameters for calculating a maximum data sending rate as follows:

\[
T = \frac{1}{4RTT} \left( 3 + \sqrt{25 + 24 \left( \frac{1 - \omega}{\pi - \omega} \right)} \right)
\]

(1)

Where \( T \) denotes the packet numbers which sender can send this time, RTT denotes the round trip time, \( \omega \) and \( \pi \) denotes the total packet loss rate and wireless packet loss rate on this link.

ARC is not an ARQ protocol and the source does not perform retransmission due to time-out. It contain two periods for higher throughput: Probe Period and Steady Period. In Probe Period ARC source sends probe packets at target rate which is a default value by source applications. After this period it use Equation.(1) to control data transmission rate.

[2] proposed a modified TFRC module named MULTFRC to open multiple connections of TFRC flows and improves it's performance. The equation MULTFRC calculates a optimal connection number by using bandwidth, wireless packet loss rate and round trip time.


3. Proposed Scheme

When the increasing queue reaches the maximum limit of the buffer in this link, the following packets will be dropped. The ratio of packets dropped will be approximated as the ratio of queued packets. This ratio can be formulated by inter-arrival jitter and defined as following:

\[
J_R = \frac{D_{JR}(i-1,i)}{t_R(i) - t_R(i-1)}
\]

(2)

where

\[
D_{JR}(j,i) = (R_j - R_i) - (S_j - S_i)
\]

(3)

[4] defines threshold of jitter ratio by congestion window size. This threshold denotes the transmission rate of packets which a congestion may happens. TFRC is a equation based rate control scheme so it do not contain a congestion window parameter in it's equation. Therefore, we most model a TCP-behavior model for TCP-Friendly characteristic while we combine Jitter-ratio into rate control scheme.

[1] uses the static state TCP-behavior model for formulating its equation. The main issues wireless TCP studies in how to distinguish a wireless loss (WL) from congestion loss (CL) during a loss cycle (LC) in Figure.2. The less misjudge of wireless loss event and congestion loss event the more performance will be improved. Each LC starts and ends with CL event arrival. The throughput is shown as follows:

\[
T = \frac{\bar{X}}{\bar{D}}
\]

(4)

Where \( \bar{X} \) denotes total packets were sent in one LC, \( \bar{D} \) denotes congestion window size, \( \bar{N} \) denotes duration of LC and \( \bar{Ni} \) is the number of RTTs in LC. \( \bar{X} \), \( \bar{D} \), \( \bar{N} \) and \( \bar{Wi} \) are expectations obtained from \( \bar{X} \), \( \bar{Di} \), \( \bar{Ni} \) and \( \bar{Wi} \). And congestion window size can be denoted as follows:

\[
\bar{W} = 2\bar{N}
\]

(5)

The total packets \( \bar{X} \) sent in the LC are and duration are follows:

\[
\bar{X} = \frac{1}{2} \left( W_{i+1} + \frac{W_i}{2} - 1 \right) \bar{N}
\]

(6)
\[ D = \bar{N} \times RTT \]  

We combine Equation (6) with Equation (7), and then \( X \) can be formulated as follows:

\[ \bar{X} = \frac{1}{2} (3\bar{N} - 1)\bar{N} \]  

(8)

Define \( tR(i) - tR(i-1) \) as \( R \), \( tS - tS(i-1) \) as \( S \). From Equation (2) and [4] the threshold of congestion window size \( cw \) which a congestion loss event may happen can be formulated as:

\[ J_r = \frac{D_{jr}(i-1,i)}{R} = \frac{\bar{R} - \bar{S}}{R} = \frac{k}{cw} = \frac{k}{2\bar{N}} \]  

(9)

Then \( N \) can be formulated as:

\[ \bar{N} = \frac{k\bar{R}}{2(\bar{R} - \bar{S})} \]  

(10)

From Equation (4) and packet size \( s \) we can formulate a maximum rate of JRC transmission as:

\[ T \times s = \frac{(3\bar{N} - 1)\bar{N}s}{2\bar{N} \times RTT} = \left( \frac{(3k - 2)\bar{R} + \bar{S}}{4RTT} \right) \]  

(11)

The usage of Equation (11) in JRC is as same as maximum data transmission rate equation TFRC, we use this rate to be a maximum transmission rate. JRC uses AIMD increase algorithm for transmission rate when the flows do not touch this threshold and decrease algorithm for congestion event happens.

If \( R > S \) that means other traffics of this connection path are increasing, queuing time of packets become longer. \( S \geq R \) and it means other traffics in this connection path are decreasing. If network condition becomes worse (\( R > S \) and \( R \) increase) than the maximal transmission rate calculated by Equation (11) will decrease. In JRC, when \( S \geq R \) that means we can have larger data transmission rate of this connection if necessary.

4. Simulation Results

JRC is a rate control scheme for real-time traffic over wired-wireless hybrid links. We simulate JRC performance by NS-2 simulation. The connections are denoted by JRC(1) to JRC(N), TFRC(1) to TFRC(N) and TCP(1) to TCP(N). The wireless link bandwidth will be defined later and random packet loss rate are simulated from 0% to 8%. Each node contains DropTail type queue. In order to show JRC’s performance and TCP-friendly, we examine two issues: TCP-Friendly simulation and performance simulation.

After lots of simulating, we default \( k \) in Equation (11) as 7.7 for our simulation for it's better TCP-Friendly and higher throughput.

4.1. TCP-Friendly

To examine JRC’s TCP-Friendly characteristic, we simulates 4 JRC traffics and 4 TCP traffics without TFRC connection. TCP traffics start at 1st second and terminate at 200th second. JRC traffics start at 70th second and terminates at 140th second. In packet loss rate in all-wired environment (0% random loss rate) shows in Figure 3 and 1% wireless random loss rate environment shows in Figure 6. Bandwidth/Delay of Figure 3 and Figure 6 in Link 1 is 100Mb/5ms, Link 2 is 5Mb/80ms and Link 3 is 100Mb/40ms.

![Figure 3. TCP-Friendly test Topology 1](image1)

![Figure 4. TCP-Friendly performance in all-wired (0% random loss rate) environment](image2)
We show the different TCP-friendly performance in Figure.4 and Figure.7. Figure.4 shows the TCP-Friendly performance in no random loss environment. We define the TCP-Friendly value by JRC-throughput/TCP-throughput. If this value equals to 1 than it means that JRC is friendly with TCP. JRC plays good TCP-Friendly characteristic in no-loss scenario shows by Figure.5. In Figure.7 we can see that JRC keeps TCP-Friendly and it has better performance than TCP in wired-wireless hybrid link.

4.2. Performance in wired-wireless hybrid environment

In this section, we compare JRC's throughput with TFRC and TCP in wireless link location issue. Therefor, we get 2 scenarios for Figure.8 and parameters define in follow sections. Each of these protocols have 8 connections for total throughput comparison.

<table>
<thead>
<tr>
<th>Wireless Link</th>
<th>Bandwidth (Mb)</th>
<th>Delay (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link 1</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>Link 2</td>
<td>64</td>
<td>80</td>
</tr>
<tr>
<td>Link 3</td>
<td>100</td>
<td>40</td>
</tr>
</tbody>
</table>

Performance of this scenario are shows as Figure.9. Then we set Bandwidth/Delay of Figure.8 to Link 1 as 100Mb/5ms, Link 2 as 64Mb/80ms and Link 3 as 100Mb/40ms.

<table>
<thead>
<tr>
<th>Link 1</th>
<th>Link 2</th>
<th>Link 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless Link</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>100Mb</td>
<td>64Mb</td>
</tr>
<tr>
<td>Delay</td>
<td>5ms</td>
<td>80ms</td>
</tr>
</tbody>
</table>

Performance of this scenario are shows as Figure.10. We can see that throughput performance are almost the same weather wireless link locates.
4.2.2. Performance of JRC, TFRC, JTCP and TCP.

To introduce JRC, TFRC, JTCP and TCP performance we have following setting: no bottleneck link, emulating WirelessMAN environment. Our topology shows as Figure 11. In this scenario bandwidth/delay of Link 1 is 100Mb/5ms, Link 2 is 64Mb/80ms and Link 3 is 100Mb/40ms. In this scenario there are 8 JRC connections, 8 TFRC connections and 8 TCP connections run together from simulation time 0sec to 100sec. Their throughput shows in Figure 12. We can see that performance of JRC and JTCP are almost the same in packet loss rate from 0% to 3%.

5. Conclusion and Future Work

In coming generation, Wireless Metropolitan Area Network (WMAN) plays important role in network establishment. The wireless link do not publish in last-hop or first-hop anymore. However, most existing solutions of equation-based rate control for wireless links are using the wireless-link parameters and might not performance better in such hybrid link.

In this paper, we introduced the JRC, an end-to-end rate-control scheme designed for real-time service regardless where a wireless-link is located or deployed. Our simulation show that JRC does have better
performance than TFRC in random-loss environment, and carries the characteristic of TCP Friendly.

However, k in Equation (11) is not constant. k should change while network condition varying. Even though we provided the solution for challenging issues of wireless environment characteristics, that is still not a optimal solution for highly changeable network and topologies. As we mentioned above, rate control schemes should be better performance and TCP-Friendly. Once network condition changed, k should be changed. How to find a optimal k is the most important issue for better TCP-Friendly and performance.

References


