Performance of Multimedia Rate Control Protocols in InterPlaNetary Internet

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***Abstract*—The communication requirements of the next generation space missions necessitate to address the challenges for the realization of the InterPlaNetary (IPN) Internet. The multimedia flows carrying audio and visual information, including planet images and scientific observations, will constitute significant portion of the traffic in the IPN Internet. In this letter, the effects of propagation delay, link errors, and blackouts on the throughput performance of multimedia rate control protocols are investigated in IPN Internet. The analytical observations and experimental results show that the existing multimedia rate control protocols are far from satisfying the IPN Internet communication requirements.**

***Index Terms*—Congestion control, high propagation delay, InterPlaNetary (IPN) Internet, multimedia rate control protocols.**

I. Introduction

THE InterPlaNetary (IPN) Internet is envisioned to provide communication services for scientific data delivery and navigation services for the explorer spacecrafts and orbiters of the future deep space missions [3]. The IPN Internet communication architecture will consist of IPN Backbone Network, Planet Networks, and IPN External Networks [2]. The most challenging part of this architecture is the IPN Backbone Network, which is composed of deep space communication links characterized by extremely high propagation delays, link errors, blackouts, and bandwidth asymmetry [2].

The multimedia flows carrying audio and visual information including planet images and scientific observations will constitute significant portion of the traffic in the IPN Internet. The rate control for the multimedia traffic of live or stored media streaming is essential to avoid network congestion, unfairness and even starvation of other flows such as reliable data transport traffic. Many multimedia rate control protocols [4]–[7], proposed for terrestrial networks, can be categorized into two, i.e., AIMD-based (Additive Increase Multiplicative Decrease) and equation-based.

AIMD-based rate control protocols are TCP-compatible, i.e., they compete reasonably fairly with the existing TCP by following TCP behavior to conservatively update the sending rate based on feedback information [5]–[7]. SCTP (Stream Control Transmission Protocol) [6] implements TCP-like mechanisms such as slow start. RAP (Rate Adaptation Protocol) [5] is a rate-based congestion control mechanism for wired and short distance networks. RCS (Rate Control Scheme) [7] is a rate control scheme for real-time traffic in networks with high bandwidth-delay products and lossy links. However, all of these existing AIMD-based rate control protocols [5], [7] are developed based on the assumption that the propagation delay is relatively short, which does not hold in the IPN Backbone Network links.

On the other hand, equation-based rate control protocols [4] are proposed to provide relatively smooth congestion control for multimedia traffic in the terrestrial networks. TFRC (TCP Friendly Rate Control) [4] is an equation-based rate control scheme which adopts the TCP throughput model in its congestion control mechanism. Since the steady-state throughput model of TCP source is highly sensitive to RTT values, the equation-based rate control schemes cannot achieve high link utilization in IPN Network. In this letter, we investigate the performance of existing multimedia rate control protocols in the IPN Internet.

II. Analytical Observations

The effect of round-trip time (RTT) on the throughput can be inferred from the steady-state throughput model obtained for generic AIMD multimedia rate control protocols in [1]. The asymptotic throughput equation as a function of packet loss probability p and RTT is given in [1] as

$$\mathcal{T}^{r}_{\alpha,\beta}(p,R) = \frac{\alpha}{4(1-\beta)}\left[1+\beta+\sqrt{(3-\beta)^2+\frac{8(1-\beta^2)}{\alpha R p}}\right] \tag{1}$$

where α and β are additive-increase and multiplicative-decrease parameters; R is RTT; and the p is the packet loss probability.

In Fig. 1, the throughput estimated with the analytical model of the generic AIMD multimedia rate control protocols is shown for $p = 10^{-3}$ and $10^{-3} \leq \mathrm{RTT} \leq 10^{3}$ s. The throughput of the rate control protocol is inversely proportional to square-root of RTT and decreases drastically for increasing RTT. Although higher (α,β) values increase the estimated throughput as shown in Fig. 1; at $\mathrm{RTT} = 1000$ s, i.e., approximately 16.7 min, the achievable throughput degenerates to 10 packets/s, 25 packets/s and 67 packets/s for (α,β) of (5, 0.5), (10, 0.6) and (20, 0.7), respectively. Note that $\mathrm{RTT} = 16.7$ min is in the range of possible RTT values that can be experienced in deep space communications, e.g., between Mars and Earth.

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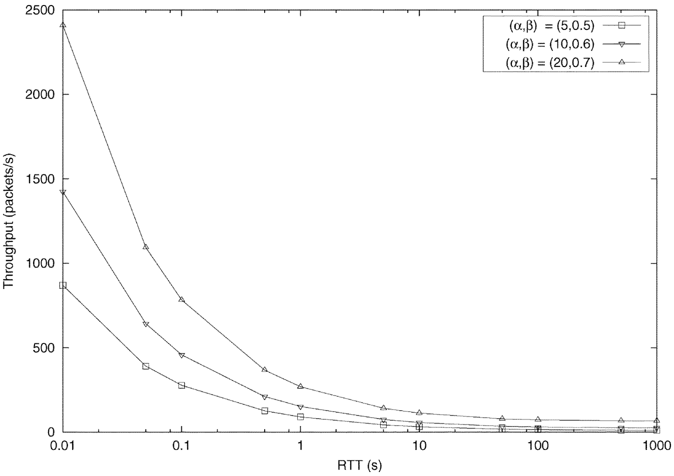

Fig. 1. Throughput for changing RTT from steady-state model.

TABLE I
RTT RANGES USED FOR THROUGHPUT PERFORMANCE EVALUATION

RTT $Range$	RTT_{Min}	RTT_{Max}
Low	0.001s	1s
High	1s	100s
Very High	100s	2400s

III. PERFORMANCE EVALUATION EXPERIMENTS

A. Propagation Delay

We use *ns*-2 to simulate the throughput performance of SCTP [6], RAP [5], RCS [7] and TFRC [4]. The experiments are performed with a very simple topology in order to isolate the effect of each factor under exploration. The source and destination are connected through 10 Mb/s link, which is assumed to have packet loss probability (P_{Loss}) of 10^{-5} unless otherwise stated. The protocols are assumed to be implemented at the source and destination endpoints of the IPN Backbone Network link, i.e., the outer-space planet and the Earth. For RCS, the target data rate, S_{Target}, i.e., a protocol parameter specifying the target transmission rate [7], is set to be 10 Mb/s. The simulation time is $30 \cdot \text{RTT}$ in all of the experiments. We observe the propagation delay effect for three different RTT ranges, i.e., low, high, and very high as shown in Table I. In this table, very high RTT range covers RTT values representing deep space communication links.

In Fig. 2, throughput values of all existing multimedia rate control protocols are around 1200 KB/s for $\text{RTT} = 1$ ms. For $\text{RTT} = 0.5$ s, the link utilization achieved by all rate control protocols drop more than twice in magnitude. The major reason for performance decrease with increasing propagation delay is that the longer propagation delay is experienced, the slower transmission rate increase and hence lower throughput can be achieved. For $\text{RTT} = 1$ s, RCS improves throughput by approximately 1500%, 712%, and 182% over RAP, SCTP, and TFRC, respectively. This is mostly because of the *Initial State* and *Steady State* algorithms of the RCS scheme [7] specifically designed for high bandwidth-delay product links.

The throughput achieved for all protocols keep decreasing drastically for high RTT ranges, as shown in Fig. 3. However, the effect of high delay on the protocols are not equal. Note that due to its TCP-like mechanisms such as slow start, SCTP performance degrades faster for $1\text{ s} \leq \text{RTT} \leq 100$ s. For $\text{RTT} = 100$ s, RCS achieves 42 KB/s throughput which is several orders of magnitude throughput improvement over the other schemes.

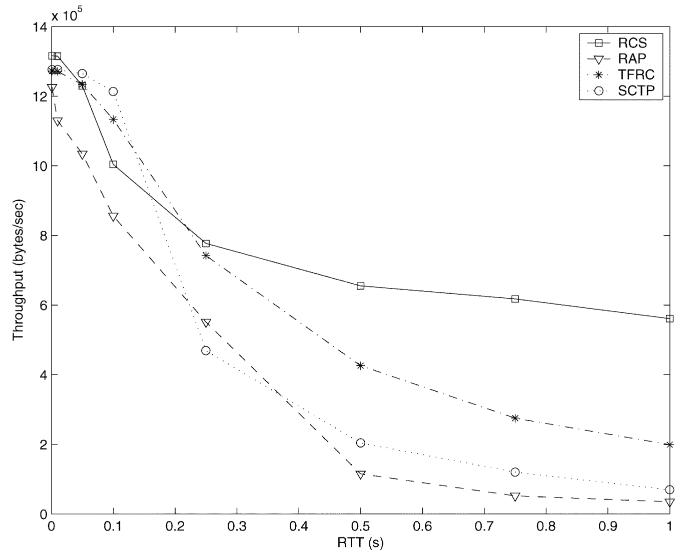

Fig. 2. Throughput of rate control protocols for low RTT ranges.

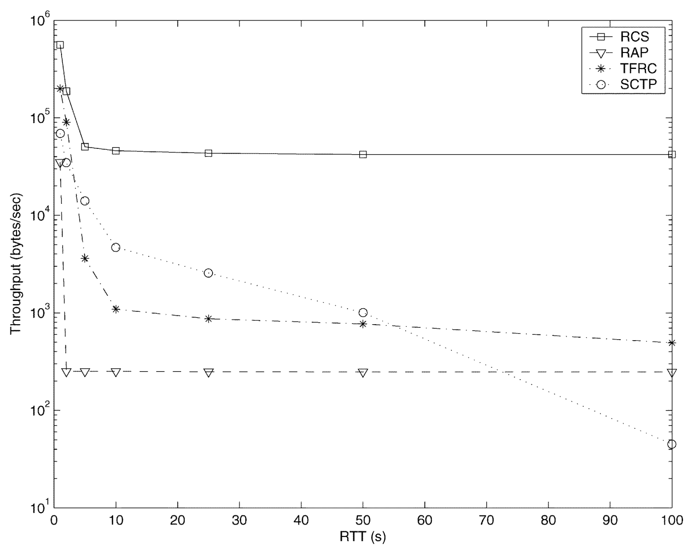

Fig. 3. Throughput of rate control protocols for high RTT ranges.

In Fig. 4, we show the throughput performance for very high RTT values including the RTT range for communication links between Mars and Earth, i.e., 9–50 min based on the orbital location of planets. In this case, the throughput achieved by TFRC and SCTP protocols drops below 100 B/s, and RAP performance drops to 237 B/s. This decrease is very drastic and the entire link remains almost unutilized. Although RCS outperforms other schemes for high RTT values, the performance degradation is still serious that it can only utilize 41 KB/s of the 10 Mb/s link for 40 min RTT.

B. Link Errors

The recognition of a packet corruption due to space link error as congestion loss leads to unnecessary rate decrease and hence severe throughput degradation. This problem is amplified with extremely high propagation delay, since it takes longer time to recover from unnecessary data rate throttle.

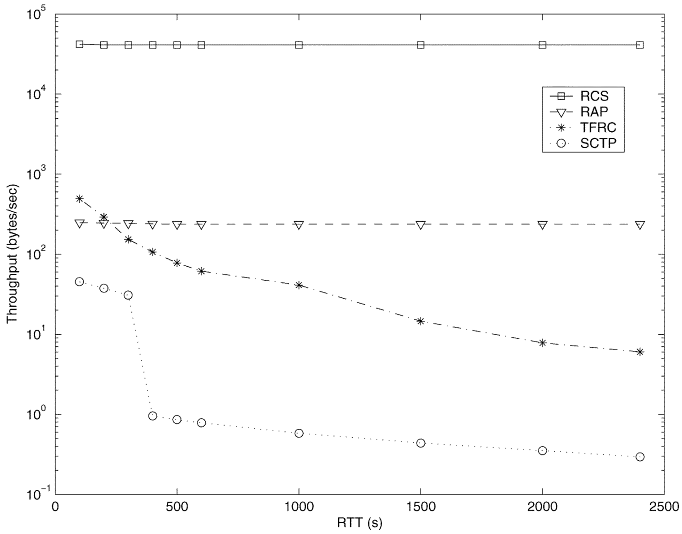

Fig. 4. Throughput of rate control protocols for very high RTT ranges.

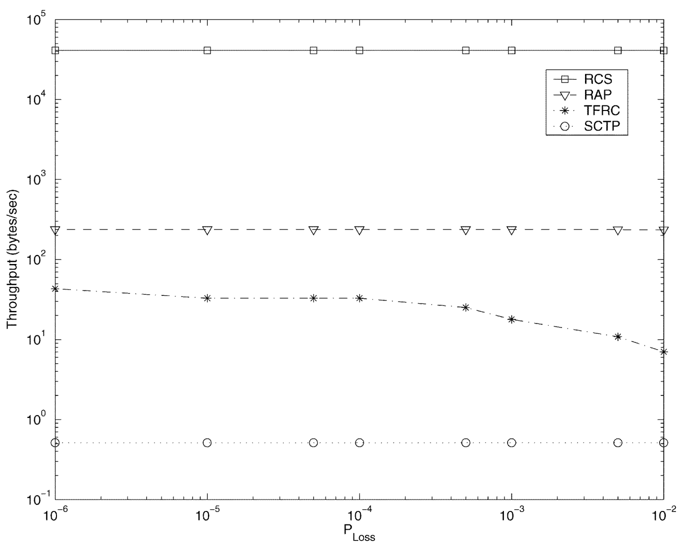

Fig. 5. Throughput for varying packet loss rates with $\mathrm{RTT} = 20$ min.

To observe the effect of link errors, we perform simulations with the same topology and $\mathrm{RTT} = 20$ min for changing packet loss rate (P_{Loss}). In Fig. 5, the results show that increase in packet loss probability does not significantly affect the throughput achieved by all protocols except TFRC. The reason for this is that AIMD protocols already reach to their lowest achievable throughput values due to extremely high RTT. Therefore, high propagation delay is dominant challenge for throughput performance in deep space links. However, since TFRC updates the data rate using the equation, which is a function of P_{Loss}, its throughput degrades with increasing P_{Loss}, as shown in Fig. 5.

C. Blackouts and Bandwidth Asymmetry

To observe the effects of link outages on the throughput performance, we perform simulation experiments where a blackout occurs at $t = 4800$ s of the entire simulation time of 12 000 s. As shown in Fig. 6, the throughput achieved by the multimedia rate control protocols slightly decrease with increasing blackout duration (note the log-scale). While this shows that

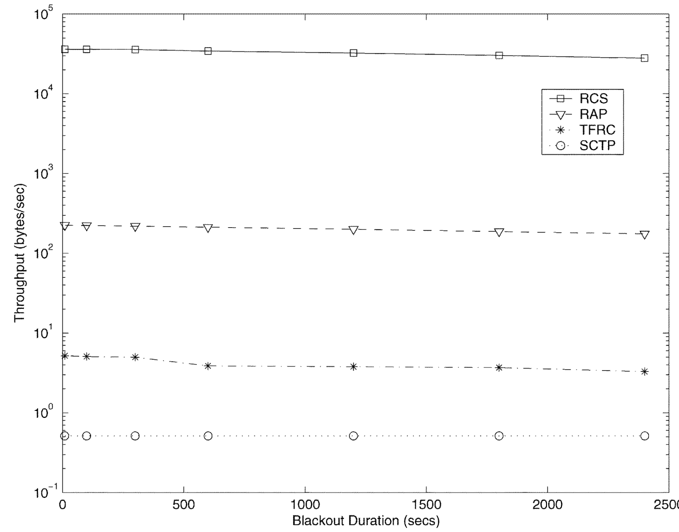

Fig. 6. Throughput for varying blackout durations with $\mathrm{RTT} = 20$ min.

blackout duration affects the throughput performance, its effect is again dominated by high propagation delay causing drastic throughput degradation.

Furthermore, we have also performed simulation experiments to observe the effects of bandwidth asymmetry. However, since the throughput achieved on the forward link, i.e., from the source to the receiver, is already too low due to high propagation delay as shown in Fig. 4; no congestion was experienced in the reverse link and hence the effect of bandwidth asymmetry could not be observed in the simulations.

IV. Conclusions

In this letter, we have shown via analytical observations and simulation experiments that the existing multimedia rate control protocols provide very poor performance on IPN Internet. The high propagation delay is the dominant challenge to be addressed in order to meet communication requirements for deep space missions. Hence, there exists an urgent need for novel rate control protocols which address these challenges and hence achieve high performance multimedia delivery in the IPN Internet.

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