Model Based Analysis on Soft State Signaling Protocols

Yangcheng HUANG, Dimitrios Miras and Saleem N Bhatti

Department of Computer Science, University College London, Gower Street, London WC1E 6BT

Abstract: The concept of soft state was introduced in the late 1980s and has been widely used in various Internet protocols. However, there is still no comprehensive understanding or well-accepted models on performance (resilience, robustness etc.) of soft state protocols. This paper presents a model based analysis on resilience of soft state signalling protocols based on probability theory. The model could be used to evaluate failure recovery time in the presence of state inconsistency for protocols such as RSVP. This work in progress aims towards an accurate and comprehensive model for signalling protocols.

1 Introduction.

Soft state [1] is a mechanism widely used by communication protocols in which nodes maintain state consistency through periodic refresh messages. Despite its wide use in Internet protocols (RSVP, PIM, RTP, SRM, SAP etc), understanding of soft-state is still vague and usually defined operationally [2] [3]. Up till now, there are no well-defined mathematical models or paradigms for soft-state signalling protocols.

This paper presents a model based analysis of a soft state mechanism. Several aspects of performance signalling protocols are discussed; to gain a better understanding of the signalling process, a resilience model for signalling communication is presented; we conduct a preliminary analysis to characterize resilience behaviour based on probability theory.

The main contributions of this paper include: (1) defining performance metrics for soft-state signalling protocols; (2) studying the resilience behaviour of soft-state protocols through a failure recovery model.

2. Performance Metrics of Signalling Protocols.

Generally the performance of Internet protocols can be evaluated from many aspects, such as traffic overhead (cost), complexity, robustness, reliability, resilience (failure recovery), consistency and adaptability. Existing metrics of generic signalling performance models include *consistency* and *cost*. The models analyze consistency ratio and cost under a range of factors, such as channel loss rate, refresh timer interval and session length [3]. For example, in [2], the consistency metric is defined as “the probability that, at time *t*, the tuple corresponding to key *k* is the same at both sender and receiver”, while the average system consistency metric is defined as “the average of the instantaneous system consistency over the lifetime of the system”. In [3], consistency is evaluated by summing the stationary probabilities of the consistent states in a proposed Markov model.

Consistency may be the most straightforward performance metric for signalling protocols, since the aim of a signalling protocol is to achieve state consistency between nodes. However, such a metric may not be sufficient in performance evaluation. In [4], robustness is defined as “the protocol’s performance under a variety of network conditions is above an acceptable threshold, but need not be optimal”. Correspondingly, this paper defines *resilience* and *adaptability* of signalling protocols as follows.

Resilience characterises the protocol’s performance under various failures (including message loss during delivery and internal state corruptions) can be recovered within an acceptable temporal threshold; such a temporal threshold is calculated by failure recovery time (FRT) in our proposed resilience model. Resilience differs from consistency since (1) failure (such as message loss) may not lead to inconsistency, but would have an effect on state recovery (caused by internal corruption); (2) state setup brings inconsistency [3], however it is uncorrelated with resilience.

Adaptability means the protocol's behaviour could be tuned according to the status of the hosting environment, such as available bandwidth resources and channel loss rate, in order to achieve state consistency with low overhead. Compared with consistency, adaptability emphasizes the protocol's capacity in sensing the state of the hosting environment such as resource availability and tuning parameters such as refresh timer interval by itself.

Specifically, this paper only studies resilience behaviour of state refresh process in signalling protocols.

3. Resilience Model for State Refresh Process.

Signalling protocols may experience several types of potential failures. For example, an RSVP daemon may crash or restart because of a router rebooting or power-off; RSVP nodes may lose reservation state caused by such failure. As discussed in [5], RSVP uses soft-state to address such *internal state corruption* by periodically sending a full representation of installed state in RESV and PATH messages.

3.1 Trigger and Refresh Process

In RSVP, signalling messages can be categorized into two types: *trigger* and *refresh* messages [7]. Trigger messages are generated due to "state changes", including "the initiation of a new state", route change that altered the reservation paths or "a reservation modification by a downstream router" [7]. PATH, RESV, PATHTEAR and RESVTEAR are trigger messages in RSVP. Refresh messages contain "replicated state information" to update state for robustness. PATH and RESV messages sent after setting up RSVP sessions are refresh messages.

Based on this terminology, this paper categorizes the signalling process into two stages: trigger (or state setup) and refresh process. These two processes share similar message format and message data. However, they differ significantly in their objectives and purpose:

(1) Control mechanism. Essentially, the trigger process is based on use of best effort traffic messages with hard state mechanism [3] effectively; an acknowledgement is used to achieve the reliability in message delivery; state refresh is based on a soft-state mechanism.

(2) Performance metrics. Overhead is the main concern of the refresh process, while reliability is the main concern for the trigger process.

The following sections present a resilience model for the state refresh process. Note that the proposed model only discusses recovering state inconsistency caused by internal state corruption [5].

3.2 Refresh Process Modelling without Channel Loss

Assume refresh messages are sent with period (refresh timer interval) r.

Assume that state corruption events occur according to a Poisson process of rate λ; this assumption has been made by statistical methods for reliability theory [8]; this model comes about when the inter-arrival times between failures are independent and identically distributed according to the exponential distribution, with parameter λ.

The *failure recovery time* (FRT) in one refresh period r is defined as the time from the occurrence of first failure until the end of the period. Note that, the failure recovery time is also the state inconsistency time for the system.

Consider an arbitrary period, starting at t_0. Let X be the time of first failure occurrence after t_0.

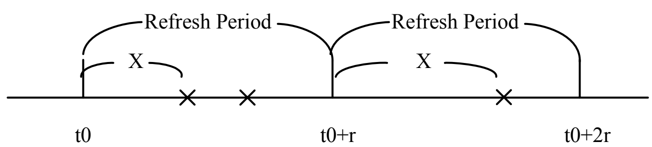

Fig 1 Refresh Model without Channel Loss

According to above definition, FRT= $(t0+r-X)^+$; also, according to the assumption, $X-t_0 \sim Exp(\lambda)$.

Therefore, the expected failure recovery time is

$E(t0+r-X)^+ = E(r-\gamma)^+$ (where $\gamma=X-t_0 \sim Exp(\lambda)$)

$$= \int_0^\infty (r-\gamma)^+ \lambda e^{-\lambda\gamma} d\gamma = \int_0^r (r-\gamma)\, \lambda e^{-\lambda\gamma} d\gamma$$

$$= r + \frac{-1 + e^{-r\lambda}}{\lambda} = \varphi(r)$$

The *failure recovery ratio* (FRR) of one period *r* is defined as the fraction of inconsistency time in the period.

Therefore, the expected failure recovery ratio (FRR) without channel loss is $1 - \frac{1-e^{-\lambda r}}{\lambda r}$

3.3 Refresh Process Modelling with Channel Loss

Let Y be the time of first failure occurrence after last state refresh. $Y \sim Exp(\lambda)$

For a refresh interval with length S, the expected failure recovery time (or expected time under inconsistent state) is $E(S-Y)^+ = g(s)$; among *n* refresh intervals, the total time spent under inconsistent state is n g(s);

Let *p* be the channel loss rate. With channel loss, the length of the refresh interval observed at one node can be r, *2r … k r*, subject to certain possibility. Let S be the length of a typical refresh interval. S is a random variable.

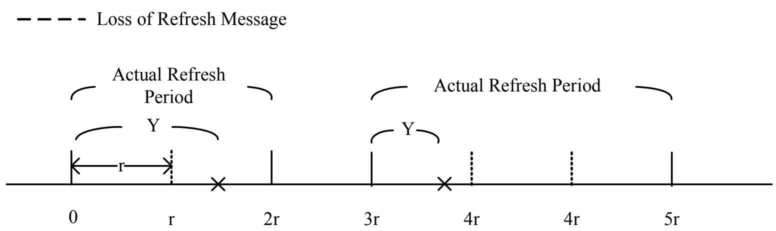

Fig 2 Refresh Model with Channel Loss

$P(S=r) = 1-p$

$P(S=2r) = p(1-p)$

$P(S=k\,r) = p^{k-1}(1-p)$

According to the Geometric distribution density function, $S \sim r\,Geom(1-p)$.

$E(S) = r/(1-p)$

$E(S-Y)^+ = E(\varphi(S)) = \sum (\varphi(k\,r)\, p^{k-1}(1-p)) = \varphi(r)(1-p) + \varphi(2r)\, p(1-p) + \ldots + \varphi(k\,r)\, p^{k-1}(1-p) + \ldots$

$$= \frac{r}{1-p} - \frac{e^{r\lambda}-1}{e^{r\lambda}-p}\,\frac{1}{\lambda}$$

Then the expected failure recovery ratio (FRR) is n g(s)/ n E(S) = g(s)/ E(S).

Therefore, the expected failure recovery ratio (FRR) with channel loss is

$$\frac{\frac{r}{1-p} - \frac{e^{r\lambda}-1}{e^{r\lambda}-p}\,\frac{1}{\lambda}}{\frac{r}{1-p}} = 1 - \frac{e^{r\lambda}-1}{e^{r\lambda}-p}\,\frac{1-p}{\lambda r}$$

From this equation, refresh interval *r* and failure rate λ have a large effect on resilience behaviour of soft state protocols. This explains the fact that tuning the refresh interval *r* could gain a better performance in resilience. Quantitative analysis on such effects will be presented in our future work.

4. Related Work

There have been several model based approaches on performance analysis of signalling protocols. Raman et al [2] develops an open-loop multi-class queuing model for soft-state based communication to analyze the consistency behaviour and bandwidth consumption behaviour given different data arrival rates, loss rates and session expiration rates. The transmission channel between sender and receiver acts as a "service"; consistent state and inconsistent state are inputs of the queuing system. However, there are some flaws in its model analysis:

(1)Loss of trigger messages brings inconsistency in inputs to the queue. However, loss of refresh message may not cause inconsistency until state expires at the receiver. Thus, even if refresh messages are lost during delivery with probability p, such a loss still brings consistency input to the queue.

(2) According to [6], the scheduling of the server in [2] is not *FCFS* (First-Come-First-Serve). Because of space limitation, the details are not given in this paper.

Ping et al [3] uses a continuous time Markov model to quantify state inconsistency and cost in single and multi-hop signalling scenarios, to compare and contrast a variety of signalling approaches.

5. Conclusions and Future Work

This paper studies the resilience behaviour of soft state protocols through a failure recovery model.

The model based performance analysis presented here is mainly theoretical; the model needs to be validated through simulations and experiments in future work;

This paper only discusses the resilience aspect of the soft state performance analysis; more work on robustness and adaptability are in progress;

The proposed model is only for the refresh process of signalling protocols. It would be interesting to model the trigger process and thus present a comprehensive model for signalling protocols.

Acknowledgments.

We are grateful to Damon Wischik and other members of the Networks Research Group at UCL for valuable comments.

References.

[1] D. Clark: The design philosophy of the DARPA internet protocols, Symposium proceedings on Communications architectures and protocols, p.106-114, Stanford, USA, August 16-18, 1988

[2] Raman, S. and Mccanne, S: A Model, Analysis, and Protocol Framework for Soft State-based Communication. Proc. SIGCOMM 1999, Cambridge, MA, Sept. 1999

[3] Ping Ji, Zihui Ge, Jim Kurose, Don Towsley: A Comparison of Hard-state and Soft-state Signalling Protocols. Proc. ACM SIGCOMM, 2003

[4] John C. S. Lui, Vishal Misra, and Dan Rubenstein: On the Robustness of Soft State Protocols. ICNP 2004

[5] Braden, R., Ed., Zhang, L., Berson, S., Herzog, S., and S. Jamin, Resource ReSerVation Protocol (RSVP) -- Version 1 Functional Specification, RFC 2205, September 1997

[6] Baskett, F., Chandy, M., Muntz, R., and Palacios, F. Open, Closed, and Mixed Networks of Queues with Different Classes of Customers. Journal of the Association for Computing Machinery 22, 2 (1975), 248-260

[7] P. Pan, H. Schulzrinne, Staged Refresh Timers for RSVP, Proc. Global Internet Conference, 1997

[8] Steven E. Rigdon, Asit P. Basu, Statistical Methods for the Reliability of Repairable Systems, John Wiley & Sons, May 2000