

Congestion Control for Adaptive Satellite Communication Systems Using Intelligent Systems

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Abstract—Broadband satellite based IP network congestion control is becoming a serious issue towards commitment of Service Level Agreements (SLAs) to honor the guaranteed Quality of Service (QoS). In satellite communication systems, the channel performance might be severely degraded due to the dynamic weather conditions leading to network congestion. The inherent large bandwidth-delay product of satellite channels impede the existing numerous congestion control schemes to be applied to satellite networks. In this paper, a new congestion index is defined to indicate the degree of the network congestion as a function of queue and weather characteristics. A novel intelligent packet dropping mechanism is designed based on fuzzy logic. Simulation results and analyses show that the newly developed congestion control method is effective and efficient for broadband satellite-based IP networks.

Index Terms — Quality of Service, Active Queue Management, Fuzzy Inferencing, Intelligent Packet dropping.

I. INTRODUCTION

Satellite networks and transmissions play a significant and major role in numerous fields. They find their application in fields of computer communications, telephone communications, television broadcasting, transportation, banking and finance, SCADA to name a few. Recent trends in telecommunications indicate that four major growth market/service areas are: messaging and navigation services (wireless and satellite), mobility services (wireless and satellite), video delivery services (cable and satellite), and interactive multimedia services (fiber/cable, satellite).

Coupling the characteristics of satellites such as wide area coverage, multicast capabilities and wide area coverage with terrestrial networks opens up vast market opportunities. Due to its extensive geographic reach, satellite communications may be the only solution in those areas where terrestrial high-bandwidth communications infrastructure is impractical or non-existent. Also satellite components have been predicted to play an important role in the third generation wireless multimedia services as a result of their wide coverage. Some of the satellite characteristics can be utilized to arrive at the satellite specific Quality of Service classes. The major drawbacks of satellite communications are the high propagation delay, due to their altitude, and the SNR (signal to noise ratio),

which can dramatically decrease with adverse atmospheric conditions.

In the satellite communications family, a new concept, broad-band satellite networks have been proposed [1]. In the last few years, the broad-band satellite network has gained tremendous research interest [2]. The broad-band satellite network is IP-based and provides a ubiquitous means of communications for multimedia and high data rate Internet-based applications, such as audio and video applications.

II. THEORETICAL BACKGROUND

A. Existing methods to control Quality of Service (QoS)

QoS is also defined by IETF as “A set of service requirements to be met by the network while transporting a flow” [3]. Objectives of QoS control is to maintain the system performance parameters (jitter, packet loss rate, queuing delay) to meet the QoS requirements defined in SLAs. Three major categories of approaches to ensure effective control of QoS are Intserv Control Model, Diffserv Control Model and Active queue management (AQM) [4]. The first two are based on flows distinction assumption. AQM can fairly regulate network traffic without any flows discrimination. This is particularly prevalent in best effort networks where all streams have the same network access right. AQM is a technique of preventing congestion in packet-switched networks. RED is one of the most well-known AQMs and many variants have been proposed since RED was developed. RED [5], an efficient queue management and congestion avoidance algorithm is discussed next.

B. Random Early Discard Algorithm

The key point of RED is to avoid network congestions by controlling the average queue length in a reasonable range. RED sets the minimum and maximum thresholds for queues and handle newly arrived packets according to the following rules:

1. IF the queue length falls in the range from the minimum threshold (q_{\min}) to the maximum threshold (q_{\max}), THEN RED drops newly arrived

packets with the probability that calculated using exponential weighted moving average (EWMA) function;

2. IF the queue length is larger than q_{\max} , THEN RED drops all newly arrived packets (i.e., Drop Tail)
3. IF the queue length is smaller than q_{\min} , THEN no packet dropping.

RED was proven to be stable [6]. However its performance is sensitive to the dynamically parameter tuning, especially the tuning of q_{\min} , q_{\max} and q_{weight} . The efforts for accurately tuning the RED parameters achieved limited success so far.

C. Intelligent Systems – Fuzzy Logic

Fuzzy Logic was first developed by L. A. Zadeh in 1965 to represent various types of “approximate” knowledge, which cannot otherwise be represented by crisp methods. Fuzzy logic is an extension of crisp two-state logic and it provides a better platform to handle approximate knowledge. Fuzzy logic is based on fuzzy sets and a fuzzy set is represented by a *membership Function (MF)*. A membership function is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. It provides the degree of membership within a set of any element that belongs to the universe of discourse. Fuzzy logic usually uses IF/THEN rules that are statements used to formulate the conditional statements that comprise the fuzzy logic. The conditional rules are stored in the knowledge base and fuzzy inferencing is done on the stored rules.

The paper is divided into the following sections. Section 3 presents the problem space being dealt with. Section 4 discusses the proposed solution, intelligent packet dropping mechanism. Simulation results and discussion is presented in sections 5 & 6.

III. PROBLEM SPACE

To provide predictable and reliable services, service providers of satellite communication negotiate Service Level Agreement (SLAs) with the customers. Designing rules necessary to maintain the SLAs for satellite-based networks are more complex than that for non-satellite networks since predictability of service in satellite-based systems are affected by external factors such as weather. It is extremely difficult to clearly engineer SLA metrics such as throughput, delay and jitter when there are uncertainties. Presently in satellite networks, when rain fade situation occurs due to excessive precipitation conditions, the capacity of ground terminal is lost and this consequently leads to loss of service. This is due to the incapability of the ground terminal to properly predict and react to the rain fade situations on its own. In addition, the hub does not have any intelligence to assist the ground terminals during rain fade situations. Lately Quality of Service (QoS) is being adopted in both ground terminals as well as the satellite hubs so that so that higher priority packets with

more stringent SLAs get serviced at the cost of low priority packets, when there is contention for bandwidth.

The challenge now is to adaptively manage the QoS in ground terminals as the throughput can change without adequate warning due to weather conditions. In this context, a novel fuzzy-based packet dropping algorithm is proposed that can be implemented as system based intelligent algorithm in the Ground Terminals. In a broad sense, these algorithms would use dynamic atmospheric conditions and SLAs as input to engineer a real-time adaptive QoS that provides the right service levels to the customers.

IV. PROPOSED SOLUTION

Fuzzy logic has been utilized to tune the dropping probability following the packet dropping / marking probability function of the RED algorithm. Non-fuzzy algorithms may be used to solve the problems of the network state. However fuzzy logic based algorithms provide a more robust non-linear solution with fewer parameters. Linguistic knowledge of fuzzy logic is used to better understand the highly non-linear and time varying behavior of the IP based networks.

A. Theory of Congestion Index

As discussed in [7], works of V.Jacobson [8] and Jain [9] have given some guidance on the design policy to tackle the problem of congestion. However, designing an algorithm that is directly based on the congestion state of the network is a more effective way to handle congestion control. In the proposed work, we define a congestion index, CI that gives a direct indication on the congestion state of the network. CI is defined as the measurement or degree of the network congestion state, whose value lies between [-1, 1] in [6] and was based on queue characteristics. However, here we extend this concept and produce a new congestion index to consider also weather uncertainty. Further, in a similar way, this can be generalized to other uncertain inputs which addresses the problem of ‘curse of dimensionality’. Lower the value of CI, lesser is the indicated load on the network.

Two look up tables were designed to deal with the non-linearities and uncertainties contributed by dynamic weather conditions and the queue characteristics. Our proposed fuzzy inference system has two inputs and one output for each of the two look up tables which uses separate linguistic rule sets for the process of inferencing.

Triangular membership functions were adopted for both the input and output sets. Fuzzy linguistic rule base was designed taking into consideration the time varying conditions of queue and weather parameters. The inferencing in the two look tables was performed based on 25 & 35 rules sets, respectively.

B. Table Look-Up 1

The first look up table deals with the dynamic real time queue characteristics obtained from the Hub/Gateway. Normalization is then performed on the queue

characteristics and fuzzy logic is invoked. The input variables for the first look up table are:

- a. Queue Length
- b. Change in Queue Length

The output variable that constitutes the table is the normalized values of the congestion index of [6].

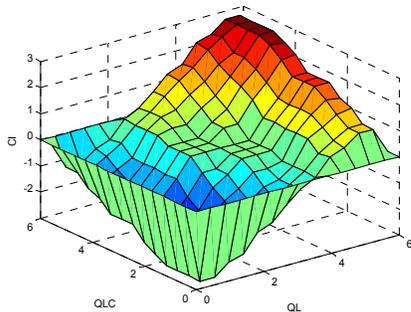


Fig 1 Output Surface of Table Lookup – 1

Fig 1 shows the output surface of Table Lookup-1 and interaction between the input-output based on rule set containing the 25 IF-THEN conditional rule set. A sample rule base is shown below. Equal weights have been given to each rule.

1. IF (*QL is Very Low*) and (*QLC is Very High*) THEN (*CI is Negative Small*)
2. IF (*QL is Low*) and (*QLC is Normal*) THEN (*CI is Zero*)
3. IF (*QL is Normal*) and (*QLC is Low*) THEN (*CI is Zero*)
4. IF (*QL is High*) and (*QLC is Very Low*) THEN (*CI is Zero*)
5. IF (*QL is Very High*) and (*QLC is Very High*) THEN (*CI is Positive Big*)

Key:

QL – Queue Length
 QLC – Queue Length Change
 CI – Congestion Index

C. Table Look-Up 2

The second look up table deals with the uncertainties contributed by dynamic weather conditions. Input variables;

- a. Weather Conditions
- b. Congestion Index (from Look up table-1)

The output variable is a new congestion index.

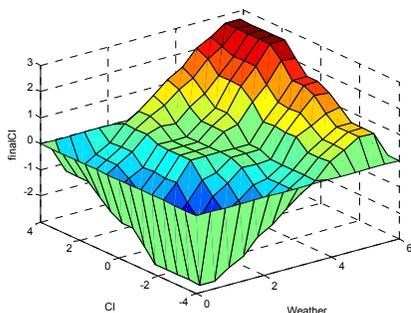


Fig 2 Output Surface of Table Lookup - 1

Fig 2 shows the output surface of Table Lookup-1 and interaction between the input-output based on rule set containing the 35 IF-THEN conditional rule set. A sample rule base is shown below. Equal weights have been given to each rule.

1. IF (*Weather is Excellent*) and (*CI is Neg Small*) THEN (*NCI is Negative Big*)
2. IF (*Weather is Good*) and (*CI is Pos Small*) THEN (*NCI is Zero*)
3. IF (*Weather is Normal*) and (*CI is Pos Med*) THEN (*NCI is Zero*)
4. IF (*Weather is Bad*) and (*CI is Pos Small*) THEN (*NCI is Positive Small*)
5. IF (*Weather is Worse*) and (*CI is Pos Big*) THEN (*NCI is Positive Big*)

Key:

CI – Congestion Index
 NCI – New Congestion Index

Hence, through the simple operation of look up table, we can get the congestion index of various network states and tune the parameters of the RED algorithm.

A parameter sensitivity test was performed to recognize the parameters that were most affected by tuning the different parameters of RED. Testing showed that the values of maximum threshold and queue weight (when tuned based on CI) were the parameters that affect the queue characteristics the most. Consequently, these parameters were chosen for tuning based on the value of Congestion Index.

Continuous tuning and updating is performed on the RED algorithm based on the newly obtained values if CI. CI is in turn continuously tuned and updated based on the incoming dynamic weather data and real time queue characteristics.

Our simulation experiences proved that it is easy to employ this kind of tuned intelligent packet dropping mechanism as the AQM mechanism effectively. The average queue size showed a marked decrease when the intelligently tuned parameters were used.

D. Summary

In summary, the mechanism could be outlined as follows,

1. Sample real time router queue length to obtain the real time queue characteristics.
2. Create database with past and current weather conditions as “Weather Changes”.
3. Perform normalization on the data available.
4. Build the first look up table with values of Congestion Index 1 with queue characteristics as input variables.
5. Build the second look up table with values of the final Congestion Index with the values of previous CI -1 and weather changes.
6. Look up into the fuzzy based look up table that contains the final congestion index values that In turn is used to tune the RED algorithm
7. With the help of the Congestion Index, tune/change the values of threshold and queue weight of the RED algorithm.

8. Observe the characteristic of the queue that is now run with the tuned parameters. Obtain the new queue characteristic and update the fuzzy look up table with the new values.

V. SIMULATION AND RESULTS

In order to evaluate the performance and robustness of our proposed solution, we set up a simulation model using the open source simulation tool NS-2. We consider the Satellite based IP network as a communication link with fixed bandwidth and large delay for the simulation. The simulation setting to model the traffic generated by a typical satellite ground terminal is listed below.

Link Capacity	2 Mbps
Link Delay	300 ms
TCP Source	10
UDP Source	2
TCP Traffic	70%
UDP traffic	30%

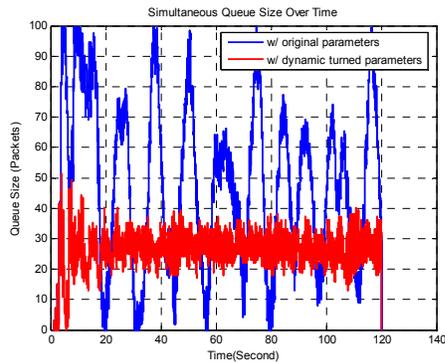


Fig. 3. Simultaneous queue size over time

The simulation is run under two scenarios. The first one is run with fixed RED parameters and the second one with dynamic turned RED parameters with aid of the values of congestion indices obtained from fuzzy inferencing. The simulation results Fig (3) & (4) show that with the intelligently tuned RED parameters, queue length stabilization can be achieved without reducing the total throughput of the ground terminal and ensuring efficient use of the network resources. By stabilizing the queue, we achieve constant queuing delay at the ground terminals, which is an important feature to achieve QoS control.

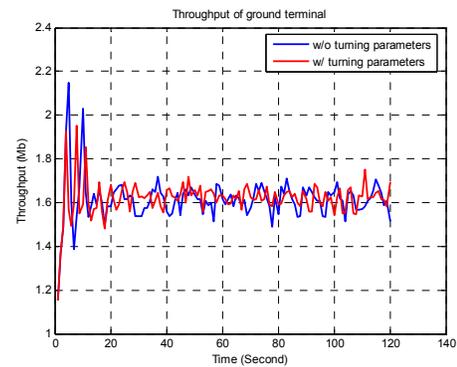


Fig. 4. Throughput of the ground terminal

VI. CONCLUSION AND FUTURE WORK

In this paper, we introduced a novel intelligent packet dropping mechanism that can be incorporated into the high level design of broadband satellite-based IP network to contend with inherent impacts of dynamic weather changes on the system performance. A network congestion mechanism based on RED with fuzzy inferencing is proposed for such satellite-based IP networks. The research carried out so far strongly reiterates the fact that AQM can be successfully achieved by intelligent-based packet dropping probability instead of the probability-based packet dropping mechanism of the RED algorithm.

REFERENCES

- [1] A. Jamalipour, Broad-band satellite networks — the global IT Bridge, Proceedings of the IEEE, Vol. 89, No. 1, Jan. 2001
- [2] T. Taleb, N. Kato, and Y. Nemoto, Recent trends in IP/NGEO satellite communication systems: transport, routing, and mobility management concerns, IEEE Wireless Communications, Vol. 12, issue 5, Oct. 2005
- [3] W.C Hardy, QoS Measurement and Evaluation of Telecommunications Quality of Service, Wiley, 2001.
- [4] B. Braden et al., Recommendations on Queue Management and Congestion Avoidance in the Internet, RFC 2309, April 1998
- [5] Sally Floyd, Van Jacobson, Random Early Detection Gateways for Congestion Avoidance, IEEE/ACM Transactions on Networking, Vol 1, NO 4, Aug 1993
- [6] H. Ohsaki, M. Murata, and H. Miyahara, Steady state analysis of the RED gateway: stability, transient behavior, and parameter setting, IEICE Transactions on Communications, Vol. E85-B, Jan. 2002
- [7] F.Yanfei, R.Fengyuan, L.Chuang, Design an Active Queue Management Algorithm Based Fuzzy Decision, Proceedings of ICCT2003
- [8] V. Jacobson and M. Karek, Congestion Avoidance and Control. Prw. ACM SIGCOMM 1988 [C], Stanford, CA.1988: 314-329
- [9] Raj Jim. Congestion Convol-and Traffic Management in AIM Nehuorlw: Recent Advances and Survey. Computer Networks and ISDN system, 1596, v01.28 (13)