Intelligent Multicast Congestion Control based on Expert-control with RBFNN for Wireless Networks

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Abstract--- Wireless networks are inherently limited by battery power and bandwidth constraints. They are characterized by mobility, random changes in connectivity, fluctuations in channel and interference due to neighboring nodes etc. Due to these factors, packet loss of a wireless network is much more than that of a wired network, in which packet loss occurs mainly due to congestion in the network. Congestion in a network is characterized by delay and packet loss in the network. This leads to the requirement for Congestion Control mechanism. Several researchers proposed various Congestion Control mechanisms based on their observation. Each has its own advantages and disadvantages. In this paper, Expert-Control based Intelligent Multicast Congestion Control (ECMCC) is proposed. ECMCC detects the network congestion state according to network relative queuing delay and packet loss, feedbacks information to multicast source based on representatives set mechanism, distinguishes between wireless link errors and network congestion, and judges the current network state, then takes different control strategies to adjust the sending rate of multicast source. The knowledge base is used in the expert controller module in the proposed technique. This knowledge base is generated using the artificial neural network called Radial Basis Function Neural Networks (RBFNN). The simulation result shows the proposed technique results in better congestion control and improves the network throughput.

Keywords--- Intelligent Multicast Congestion Control, Artificial Neural Network (ANN), Radial Basis Function Neural Networks (RBFNN), Knowledge Base

I. INTRODUCTION

In the past decade, the wireless network has experienced tremendous growth, and this growth is likely to continue in the near future. Apart from an increase in the number of users, more demanding applications will appear, resulting in ever greater resource requirements. The design of such a network, which is based on a cellular architecture, will give room for adequate use of the available frequency spectrum. A strong network backbone is needed to support connections since high quality of service without fully coordinated channel and network access is achievable. The wireless channel must be kept from reaching the congestion point, since it will cause an overall channel quality to degrade and loss rates to rise, leads to buffer drops and increased delays, and tends to be grossly unfair toward calls which has to traverse a larger number of radio hops.

Congestion avoidance and congestion control [7] are debatable issues in developing data communication networks and have received a great attention in recent years. A feedback based congestion control scheme is required to ensure trouble free data transfer in a bottlenecked network link. Also prediction of queue situation in a bottleneck node is a very useful tool for avoiding congestion in a node. There are various techniques proposed to control the congestion in the wireless network. All the techniques have its own advantages and disadvantages. When the packet error rate is larger, the throughput resulted for the existing techniques reduce more. Thus a suitable technique is required for better congestion control. This paper proposes an expert control [9] based Intelligent Multicast Congestion Control [8, 17, 18] technique which can result in better throughput [6]. The knowledge base [10] is created for the proposed technique with the help of an artificial neural network [21, 23] called Radial Basis Function Neural Networks (RBFNN).

II. LITERATURE SURVEY

Ning et al., [1] analyzed of congestion control [24] strategy for wireless network. TCP now is widely used in Transmission Control Protocol; however, in the wireless network environment, TCP congestion control typically has some defects such as high-error rate, long-latency, low-bandwidth and frequent-movement, etc. In the wireless network, the implementation difficulty of congestion control [5] mechanism is the degree of congestion, which is not only relevant to the length of the queue, but also the wireless channel around the node is busy. Many congestion control algorithms have applied in congestion control. In this paper, wireless network congestion control [19, 20] strategy takes the idea of active queue management into the implement
discarding strategy by detecting receiving and sending condition through the MAC layer in real-time, forecasting the arrival rate of the packet, as well as estimating the available bandwidth of the node. Thanks to that estimating bandwidth needn't to exchange the state information with other nodes, which reduces the overhead of the system. At the same time, the congestion control [15] mechanism eases the congestion state of wireless network, and improves the network performance.

Warrier et al., [2] proposed a Practical Differential Backlog Congestion Control for Wireless Networks. Congestion control in wireless multi-hop networks is challenging and complicated because of two reasons. First, interference is ubiquitous and causes loss in the shared medium. Second, wireless multihop networks are characterized by the use of diverse and dynamically changing routing paths. Traditional end point based congestion control protocols are ineffective in such a setting resulting in unfairness and starvation. This paper adapts the optimal theoretical work of Tassiulas and Ephremedes on cross-layer optimization of wireless networks involving congestion control, routing, and scheduling, for practical solutions to congestion control [11, 26] in multi-hop wireless networks. This work is the first that implements in real off-shelf radios, a differential backlog based MAC scheduling and router-assisted backpressure congestion control for multi-hop wireless networks. Our adaptation, called DiffQ, is implemented between transport and IP and supports legacy TCP and UDP applications. In a network of 46 IEEE 802.11 wireless nodes, we demonstrate that DiffQ far outperforms many previously proposed "practical" solutions for congestion control.

Kang et al., [3] suggested an expert-control-based multicast congestion control mechanism for wireless networks. With the increasing popularity of various multicast applications, the application of existing multicast congestion control mechanisms to wireless networks, which were designed for wired networks, is a challenging work due to high bit error rate, fading and handover. In this paper, we proposed an expert-control-based multicast congestion control mechanism for wireless networks, termed ECBMCC. In this novel mechanism, multicast receivers sent their feedback information to the expert controller rather than the sender, and the expert controller made sure the state of TCP connection by inferring according to the feedback information. With the help of expert inference, ECBMCC easily differentiated between wireless link error and network congestion, and chose the accurate congestion control policy to control the sending rate. And ECBMCC avoided the problem of feedback implosion, thus enhanced the scalability of multicast congestion control mechanism. The simulation results show that this mechanism can strengthen the congestion and random errors processing capability in real time and improve the network throughput, and this control scheme is more robust than existing mechanisms and more scalable.

Jian et al., [4] determined the Challenges and Solutions, in applying router-assisted congestion control to Wireless Networks. Router-assisted explicit-feedback congestion control [16] protocols have recently been introduced to overcome the inefficiency problem of TCP in high bandwidth-delay product (BDP) wired networks. However, two main challenges are encountered when applying this kind of congestion control [13, 14] to wireless networks. One is how to distinguish the two kinds of packet loss (non-congestion-related loss and congestion-related loss) in lossy wireless networks as well as how to react to them accordingly and properly. The other is how to probe the unknown bandwidth capacity of a wireless link which is required in calculating router feedback. Through detailed analysis of these challenges, we have proposed some practical and novel enhancements on router-assisted congestion control [20, 22] for wireless environment. We have also implemented these enhancements in a router-assisted congestion control protocol called QFCP. Simulation results using ns-2 show that it can fairly allocate wireless bandwidth resource in heterogeneous networks.

III. METHODOLOGY

Intelligent Multicast Congestion Control Framework

Considering the impact of different link layer error control methods on the upper layer, as well as handover and connection interrupted caused by host moving, wireless network state can be divided into five cases:

- **Normal state**: no packet loss and small delay;
- **Congestion state**: packet loss, large delay and overtime when the congestion is serious;
- **Connect interrupt state**: substantial packet loss, overtime and small delay;
- **Link error state**: packet loss, large delay jitter and out-of-order packets;
- **Handover state**: substantial packets loss, significant delay variation, out-of-order packets and overtime, or even connection interrupted, but the handover process is predictable.

Based on the above-mentioned analysis, considering the problems caused by applying the existing multicast congestion control algorithms to wireless networks, the author propose an intelligent multicast congestion control framework based on expert control, which is shown in Figure1.
The function of receivers is to gather network state information and calculate packet loss probability, network queuing delay and delay jitter rate, then feedback these measurement results by ACK or NACK to multicast sender. The sender consists of representative-choose module, expert controller and rate-control module. Representative choose module chooses the representatives of mobile hosts according to some performance indicators, such as network queuing delay or packet loss probability. The expert controller consists of four modules, including information extraction and procession module, inference engine, knowledge base and control pattern set. And the control object is rate-control module. The expert controller judges the different network states of wireless networks in terms of feedback messages and inference based on expert knowledge, and then executes different congestion control policies to control the sending rate. The function of ratecontrol module is to adjust the sending rate in terms of the control pattern set and TCP throughput model.

Artificial Neural Network (ANN)

The knowledge base is generated by using the Artificial Neural Network. An Artificial Neural Network (ANN) [25] is a technique based on an emulation of biological neural system. ANN is composed of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. It is an adaptive system that transforms its structure depending on external or internal information that flows through the network during the learning phase. Modern Neural Networks are non-linear statistical data modeling tools which are mainly used to model complex relationships between inputs and outputs or to find patterns in data. The greatest advantage of ANNs lies in their capability to be used as an arbitrary function approximation mechanism which 'learns' from observed data. Radial Basis Function Neural Networks (RBFNN) is used in this paper for generating the knowledge base.

Radial Basis Function (RBF) emerged as a variant of ANN. RBF is embedded in a two layer neural network in which each hidden units implements a radial activated function. The input to RBF network is nonlinear whereas the output is linear. Due to the excellent approximation capabilities of RBF networks, they are able to model complex mappings.

Radial Basis Function (RBF) is an ideal approach for modeling irregular or non-uniformly sampled dataset. A static Gaussian function is present in Radial Basis Function (RBF) networks as the nonlinearity for the hidden layer processing elements. The response of the Gaussian function is only towards a small region of the input space where the Gaussian is centered. The most suitable centers for the Gaussian functions must be found which acts as the key to the successful implementation of these networks. Supervised learning is used in this approach, but an unsupervised
approach usually produces better results. Because of this, Neuro-Solutions implements RBF networks as a hybrid supervised-unsupervised topology. Figure 2 represents the basic representation of RBFNN.

An input vector \( x \) is the input to all radial basis functions, each with different parameters. The output is a linear combination of the outputs from radial basis functions. The model starts with the training of an unsupervised layer. Its main role is to obtain the Gaussian centers and the widths from the input data. Competitive learning is used for encoding these centers within the weights of the unsupervised layer. The Gaussians widths are computed based on the centers of their neighbors during the unsupervised learning. The output of this layer is obtained from the input data weighted by a Gaussian mixture.

Once the training of the unsupervised layer has completed, the supervised segment then sets the centers of Gaussian functions depending on the weights of the unsupervised layer and determines the width of each Gaussian. Any supervised topology can be used for the classification of the weighted input.

The RBFNN has the advantage of finding the input to output map using local approximators. Generally the supervised segment is just a linear combination of the approximators. Since linear combiners have few weights, these networks are trained very fast and require fewer training samples. This RBFNN generates the knowledge base with better learned knowledge from the training sample.

### Intelligent Multicast Congestion Control Mechanism

**A. Congestion Detection and Packet Loss Differentiation**

To improve the sensitivity and reduce packet loss of multicast congestion control, ECMCC detects congestion in terms of network queuing delay and packet loss. ECMCC detects network congestion by monitoring network queuing delay in the absence of packet loss. If the sending time interval and receiving time interval of packet \( i \) and \( i-1 \) are \( S_{q_i} \) and \( R_{q_i} \), then the relative queuing delay of packet \( i \) and \( i-1 \) (termed as \( D_{q_i} \)) can be expressed as (1)

\[
D_{q_i} = R_{q_i} - S_{q_i}
\]

And the change rate of \( D_{q_i} \) (termed as \( \Delta D_{q_i} \)) can be expressed as (2)

\[
\Delta D_{q_i} = D_{q_i} - D_{q_{i-1}}
\]

In the beginning of data transmission, there is no queue in intermediate nodes. The sender sends packet to receiver without queuing delay, that is \( D_{q_i}=0 \). The network is in noncongestion state. And the sender may continue to increase the sending rate using the current increasing way. With the increasing of the sending rate, the packet is queued due to the congestion increase in the queue of immediate node, \( D_{q_i}>0 \), and the packet queuing delay is increased. The network is in congestion increase state. To alleviate the congestion, the sender must reduce the sending rate. After reducing the sending rate, if \( D_{q_i}=0 \), then the network is in stable state, the sender may keep the current sending rate unchanged; otherwise, \( D_{q_i}<0 \), then the network is in congestion decrease state, and the packet queuing delay is decreased, the sender may increase the sending rate slightly.

When there is packet loss, ECMCC distinguishes the causes of packet loss using the average delay jitter ratio \( (J_{r}) \). Average delay jitter ratio can be expressed as (3).

\[
J_{r} = \frac{D_{q_{i,j}}}{R_{q_{i,j}}}
\]

In (3), the sending time interval of packet \( i \) and \( j \) is one RTT, and \( D_{q_{i,j}} \) is the relative queuing delay of packet \( i \) and \( j \). Considering both good throughput and fairness, it can be seen that the packet loss is caused by congestion if \( J_{r}>0.05 \), otherwise packet loss is caused by link error.

**B. Representative Selection and Feedback Control**

In this paper, the representatives set mechanism is used to select congestion representatives. The number of representatives is usually 3-8, which is determined based on different groups size. The representatives are selected in terms
of three indicators with different priority, including packet loss probability (p), relative queuing delay (Dq) and feedback frequency (f). Here, the cause of packet loss is not distinguished. To improve scalability and avoid feedback explosion, usually, only the representatives need to feedback ACK to the sender for each received packet, while the receivers of non-representative use timer-based feedback control mechanism, and they send NACK (negative ACK) to the sender only after detecting a packet loss.

C. ECMCC Mechanism

1) ECMCC Mechanism Overview

ECMCC mechanism is divided into three phases:

- Slow start phase
- Normal phase
- Congestion avoidance phase

The sending rate is adjusted every average RTT to avoid reducing throughput rate excessively. In the beginning of multicast session, ECMCC uses slow start algorithm to make its transmission rate closed to its fair rate as soon as possible. During the slow start, the sending rate grows exponentially. That is, within a RTT, if \( Dq_i = 0 \), then the sending rate will be adjusted according to \( R = 2 \times \min(R, R_{rcvd}) \), where \( R_{rcvd} \) is the receiving rate. Otherwise, if \( Dq_i > 0 \), the slow start phase is end, and ECMCC goes into normal phase.

In normal phase, the sender adjusts the sending rate using the way of additive increase adaptive decrease. Expert controller judges the current network state based on feedback information. And the rate-control module adjusts the sending rate in terms of the inference results of expert controller. When there is a packet loss, the normal phase is end, and ECMCC goes into congestion avoidance phase.

In congestion avoidance phase, expert controller judges the cause of packet loss in terms of feedback information, and takes different control strategies to adjust the sending rate. If the packet loss is caused by network congestion, the sender adjusts the sending rate in terms of TCP friendly formula to ensure TCP-friendliness. Otherwise, the sender reduces the current sending rate slightly. After the congestion has been removed, if there is no packet loss within a certain period, ECMCC goes back to normal phase.

2) Inference of Expert Controller

Expert controller judges the different network states of ECMCC algorithm on normal phase and congestion avoidance phase by inference. The inference process of expert controller can be expressed as follows:

S1: Receive an ACK, and \( Dq_i > 0, \Delta Dq_i > 0 \). \( \Rightarrow \) The network is in normal state. And the sender may reduce the current sending rate.

S2: Receive an ACK, and \( Dq_i > 0, \Delta Dq_i \leq 0 \). \( \Rightarrow \) The network is in normal state. And the sender may reduce the current sending rate slightly.

S3: Receive an ACK and \( Dq_i = 0, \Delta Dq_i > 0 \). \( \Rightarrow \) The network is in normal state. And the sender may keep the current sending rate unchanged.

S4: Receive an ACK, and \( Dq_i = 0, \Delta Dq_i \leq 0 \). \( \Rightarrow \) The network is in normal state. And the sender may increase the current sending rate slightly.

S5: Receive an ACK, and \( Dq_i < 0 \). \( \Rightarrow \) The network is in normal state. And the sender may increase the current sending rate.

S6: Receive three duplicate ACK, and \( Jr > 0.05 \). \( \Rightarrow \) There is a packet loss caused by network congestion. And the sender may adjust the sending rate in terms of TCP friendly formula.

S7: Receive three duplicate ACK and \( 0 < Jr \leq 0.05 \). \( \Rightarrow \) There is a packet loss caused by wireless link error. And the sender may reduce the current sending rate slightly.

S8: Receive a NACK. \( \Rightarrow \) There is a packet loss caused by wireless link error. And the sender may reduce the current sending rate slightly.

S9: Receive several continuous NACKs. \( \Rightarrow \) There is serious error in wireless link, due to channel fading or continuous interference or high speed move and so on. It is not fit for data transmission at the moment.

S10: The timer of sender shows timeout, and \( Jr > 0.05 \). \( \Rightarrow \) The network is in congestion state. And the sender may adjust the sending rate in terms of TCP friendly formula.

S11: The timer of sender shows timeout, and \( 0 < Jr \leq 0.05 \). \( \Rightarrow \) The network connection is interrupted. And data transmission is suspended until the restoration of connection.

S12: Receive the HFN sign of handover indication. \( \Rightarrow \) The network is in handover state. And data transmission is suspended until the handover completion.

3) Decision-Making of Expert Controller

Assuming that no the change of RTT (Round-Trip Time) with the state of connection, the whole system can be regarded as a discrete time system. Each time slot \( k \) is corresponding to a...
RTT. R(k) is the send rate of the kth time slot. R(k+1) is the sending rate of the next time slot. R(0) is the initial sending rate when the connection is established at the initial time. For real-time streaming multicast, R(0) is equal to the sending rate required by the lowest QoS. For the reliable multicast, R(0) is equal to 1 packet/s. Considering the characteristics of wireless network, based on the typical congestion control algorithms, this paper conclude eight essential control rules. These eight control rules form the control pattern set U. That is,

\[ U = \{ U_1, U_2, U_3, U_4, U_5, U_6, U_7, U_8 \}, \]

\[ U_1: R(k+1) = R(k)-1; \]
\[ U_2: R(k+1) = R(k)-1/2; \]
\[ U_3: R(k+1) = R(k); \]
\[ U_4: R(k+1) = R(k) + 1/2; \]
\[ U_5: R(k+1) = R(k) + 1; \]
\[ U_6: R(k+1) = R(RTT, pc); \]
\[ U_7: R(k+1) = 4R(k)/5; \]
\[ U_8: R(k+1) = 0. \]

Among them,

\[ R(RTT, pc) = \frac{s}{RTT \left( \frac{2s}{3} + T_0 \min \left( 1, \frac{80p_s - 5}{8} \right) (1 + 32p_e^2) \right)} \]  

Equation (4) is TCP friendly formula. R(RTT, pc) is sending rate, s is the size of TCP packet; pc is packet loss event probability caused by congestion; RTT are round-trip delay; T_0 is the retransmission timeout period, generally T_0=4RTT; b is the number of received packets represented by an ACK, b is 2 if delayed ACK is used and 1 otherwise.

According to the inference, the control rules of expert controller can be expressed as:

(1) IF S1 THEN U1;
(2) IF S2 THEN U2;
(3) IF S3 THEN U3;
(4) IF S4 THEN U4;
(5) IF S5 THEN U5;
(6) IF S6 THEN U6;
(7) IF S7 THEN U7;
(8) IF S8 THEN U7;
(9) IF S9 THEN U8;
(10) IF S10 THEN U6;
(11) IF S11 THEN U8;
(12) IF S12 THEN U8.

IV. SIMULATION RESULTS

The simulation is performed on the network topology as shown in figure 3 in order to evaluate the proposed congestion control technique. The Bit Error Rate (BER) of each link is 0 for the network topology considered for simulation. Assuming that there are 4, 8, 12, 16, 20, 24, 28, 32, 36, 40 data streams respectively.

![Network Topology used for Simulation](image)

![TCP Friendly Ratio Different Number of Connections](image)

The TCP friendly ratio [12] for different number of connections by using ECMCC and the proposed congestion control technique is shown in figure 4. The TCP friendly ratio is around 1 for the proposed technique, whereas, it is not at 1 and also oscillates in case of ECMCC. This clearly indicate that the proposed technique results in better TCP friendliness when compared to the existing congestion technique ECMCC.
The throughput [6] resulted for Different Packet Error Rate by using the proposed congestion technique and ECMCC is shown in figure 5. When the Packet Error Rate is minimum, the proposed congestion control technique and ECMCC shows similar result i.e., the throughput is almost similar for both the technique. When the Packet Error Rate increases, the throughput resulted by using ECMCC decreases more whereas only few amount of throughput is reduced in case of the proposed congestion control technique. These results shows that the proposed congestion control technique results in better congestion control when compared to the existing techniques.

V. CONCLUSION

Wireless networks have become an important part of all modern day communication systems. Unlike wired networks, where bandwidth and other resources are plentiful, wireless networks are highly resource constrained, thus underscoring the need for efficient utilization of the wireless resources. An important network element is congestion control. The purpose of congestion control is to ensure network stability and achieve a reasonably fair distribution of the network resources among the users. There are different techniques exists for congestion control in wireless networks. All the available techniques results in lesser throughput when the packet error rate is higher. To overcome these issues, this paper provides an expert control based intelligent multicast congestion control technique. The expert control will provide the congestion control with the help of the knowledge base contained in it. This paper uses an artificial neural network called Radial Basis Function Neural Networks (RBFNN) for creation of knowledge base. The simulation shows that the proposed technique results in better throughput even in higher packet loss comparing to the existing techniques.

REFERENCES


