

A Compensation Mechanism for Bandwidth Allocation In IP Wireless Networks

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Abstract— Bandwidth is an important network resource type that contributes to determine the quality of service. Several research works have investigated on the issue of bandwidth allocation both in fixed networks and wireless networks. However, providing appropriate bandwidth allocation in order to satisfy the quality of service requirements and to ensure the fairness of applications in the converged environment of the new network generation is still a challenging task due to the unpredictable channel error property. This paper discuss some issues related to bandwidth allocation in wireless IP networks and proposes a compensation mechanism for the trade-off between quality of service guarantee and effective use of the limited wireless bandwidth and for ensuring the fairness in bandwidth allocation.

Keywords — QoS Control, QoS mechanisms, Next Generation Network Technologies, Multimedia & Internet services.

I. INTRODUCTION

The Next Generation Network (NGN) enables the convergence of separate networks such as telephone and computer networks (Internet) in the single network infrastructure – the all IP-based network. This network infrastructure based on both wired and wireless. In this context, providing Quality of Service (QoS) is still an urgent issue. IP, by itself, can not provide and guarantee QoS for different services to adapt with diversified requirements of applications, especially new applications. On the other hand, the new IP based NGN network is not a homogeneous environment. This network is a hybrid of different technologies. Traffics become flexible and difficult to control. Congestion and QoS degradation may occur if there is no suitable bandwidth allocation mechanism.

Bandwidth is an important network resource to ensure QoS. Many research works investigated bandwidth allocation in wired and wireless network. However, in converged environment of NGN network, suitable bandwidth allocation for applications, fair bandwidth distribution between applications are still difficult to provide due to unpredictable error in wireless channels. When error channel occurs, bandwidth allocation designed for wired system can not run properly in wireless system any more. To control and guarantee quality of service in wireless network, monitoring transmission channel, error detection, and adaptive

bandwidth allocation are necessary. In that way, we can guarantee QoS and fair bandwidth allocation for applications.

This paper discusses the issues of bandwidth allocation in wireless IP networks, proposes new bandwidth compensation for the trade-off between QoS guarantee and limited wireless bandwidth, and for ensuring the fairness in bandwidth allocation. The next sections of this paper are: section 2 presents bandwidth allocation in wireless IP network; in section 3 we propose a new bandwidth compensation mechanism; section 4 discusses some implementation issues; section 5 is conclusion of the paper.

II. BANDWIDTH ALLOCATION IN WIRELESS IP NETWORK

2.1. Bandwidth allocation mechanism classification

2.1.1. Quantitative allocation mechanism

Quantitative allocation mechanism [1] guarantee bandwidth allocation based on common parameters such as: bandwidth, latency and jitter. The quantization is done by limited defined or statistical parameters. The general method is a simulation of circuit switches, that each traffic flow can be handled separately. Incoming packets should comply with a condition of rate and maximum amount of bits. Beside, it is supposed that there is no error in the transmission links. With this supposition, a quantitative allocation mechanism can reserve bandwidth for each traffic flow and guarantee necessary delay.

Quantitative allocation mechanism is usually based on rate schedulers. The schedulers are designed by simulating fluid models of circuit switching, that can guarantee bound of delay by maintain a minimum rate during application's time.

Advantages of these mechanisms are ability to separate each traffic flow to serve, guarantee quantitative QoS for each traffic flow. Effectiveness of the mechanism and complexity are contradictions required to be solved in these mechanisms [2]. However, these mechanisms are not directly applicable for wireless networks. Schedulers for wireless networks need to consider factors such as data burst due to error channel, error due to movement, strict limited wireless bandwidth, etc. These mechanisms can not classify priority level for each service class [2].

2.1.2. Qualitative mechanism

Qualitative mechanisms [1] allocate bandwidth based on classification and assign priority level for each traffic flow. That mean higher priority level flow will be served before lower priority level flow.

Service model of these mechanisms considered change of traffic, difference of traffic flows (based on class levels), unpredictable transmission channel condition. Based on that basis, bandwidth is allocated for each flow. These mechanisms are not clearly reserved resource for each traffic flow.

There are two general methods: relative classification and ratio classification [2]. Relative classification permits to guarantee relative quality between two different flows, it mean quality of a flow is always better than the one of the other flow. Ratio classification guarantees a flow priority compared to the other and the ability to transform the ratio to control the flows according to the current circumstance.

Advantages of these mechanisms are the extension for large network, flow classification and priority assignment for each class. Classification is important due to hierarchical network structure characteristics. Beside, this mechanism can apply for wireless networks [2]. The basic shortcoming of this mechanism is the absence of the necessary level of QoS. However, this disadvantage may be limited by association with the quantitative allocation mechanism [2].

2.2. Wireless Schedulers

NGN wireless networks support a variety of applications with QoS requirements such as delay, jitter, packet loss rate, performance. To ensure QoS on demand of applications, a fundamental issue is to allocate suitable bandwidth according to application's requirements and environment conditions. Scheduling mechanisms are considered to be the main mechanism for allocating bandwidth at the packet level. This mechanism ensures the order of packets from the different flows for outgoing channel of node.

Typical schedulers have been studied in the fixed network environment. In [2] a systematic overview of these mechanisms was presented, in which WFQ (Weighted fair queuing) is the most common mechanism. However, these mechanisms are supposed for channel without errors. They also do not specify the cause of service quality degradation due to channel errors. That's why they can not be applied directly to the wireless network environment.

There have been many studies on the schedulers for wireless networks. These mechanisms are usually modified from the mechanisms which were developed for fixed networks for applying to the wireless network environment. Typically mechanisms are Wireless Fair Service (WFS), Channel Independent Fair queuing (CIF-Q), Server Fair-Based Approach (SBSA), Channel State Dependent Packet Scheduling (CSDPS) (see [2] for reference). The general strategy of these mechanisms is use compensation for fair bandwidth distribution. However, most of these methods assumed that the channel is aware of conditions (good or bad).

On the other hand, compensation for some flows may disturb services of other flows. In the case of burst and extended channel errors, these mechanisms are not able to guarantee service quality, nor guarantee delay bound for competition flow.

We can consider the problem by an example as follows. In WFQ (Weighted Fair queuing), each flow i is assigned to a queue i and is given a weight to allocate bandwidth r_i . The condition to consider fairness in any time period $[t_1, t_2]$ is that the queues (the flows) always have packets waiting for transmission in this time period. In any interval $[t_1, t_2]$, if there is no change in number of flows having packets in queue, then the bandwidth allocated for each flow i is $W_i(t_1, t_2)$ satisfies $W_i(t_1, t_2)/r_i = W_j(t_1, t_2)/r_j$.

Suppose this mechanism is applied for wireless network. Consider three flows having packet to transmit in time period $[0,2]$ with $r_1 = r_2 = r_3$. Flow 1 and flow 2 have no errors, while flow 3 experiences an error during the interval $[0,1]$. If scheduler is aware of channel state of flows, it doesn't serve f_3 in $[0,1]$. Therefore, the bandwidth allocation for the flows in $[0,1]$ and $[1,2]$ is below:

$$W_1[0,1] = W_2[0,1] = 1/2$$

$$W_1[1,2] = W_2[1,2] = W_3[1,2] = 1/3$$

In $[0,2]$, bandwidth allocation is below:

$$W_1[0,2] = W_2[0,2] = 5/6$$

$$W_3[0,2] = 1/3$$

This allocation does not satisfy fairness of flows. This simple example shows the difficulty when applying WFQ for wireless environment, even in ideal conditions.

Therefore, research on the issue of bandwidth allocation for wireless IP networks remains a problem, requiring channel quality control and suitable channel compensation. That is the research topic of this paper.

III. COMPENSATION MODEL FOR BANDWIDTH ALLOCATION IN WIRELESS IP NETWORKS

3.1. Bandwidth compensation demand in wireless network environment

Example above shows the need to compensate bandwidth for ensuring fairness in wireless network schedulers. The mechanism needs to distinguish between temporary flow without packets and flow having packet to transmit but its channel is error. The compensation needs to consider the property of short-term fairness in certain time interval. Obviously, it is a compromise between the bandwidth compensation demand, the interval of unfairness, and the fairness index. There may be many different methods to compensate. According to the above example, during $[0,1]$, required channel bandwidth of f_1 is $1/3$, while f_2 can use all the additional allocated bandwidth. Thus, in $[0,1]$ the channel bandwidth allocation is:

$$W_1[0,1] = 1/3$$

$$W_2[0,1] = 2/3$$

$$W_3[0,1) = 0$$

This means f_2 receives additional $1/3$ bandwidth of f_3 , while f_1 receiving bandwidth allocation as it requires. So the question arises as how the bandwidth will be in time period $[1, 2]$ allocated? Compensation mechanism can ensure the scheduling fairness, but other problems may arise as follows:

- How to detect channel errors, in other words, how to know when to compensate?
- Does the compensation for one flow affect other flows, and how?
- When compensation is sufficient for the traffic loss due to error channel?
- Whether the compensated flow gives up additional bandwidth? and when?
- How to compromise between the service quality and efficient use of limited wireless bandwidth.

Generally speaking, to obtain the appropriate scheduling and to resolve the issue of service guarantees in wireless networks, additional methods are necessary to detect channel errors, record service losses in order to provide compensation for the channel error flows, when they are restored again.

So far there have been many researches on this issue, for example [2-18]. There are several studies in adaptive mechanisms, such as [2,4,7], where bandwidth is allocated according to the needs of the application. Some other studies considered the ability to combine QoS and channel control, for example [3,6,11]. The characteristics and differences between the uplink and downlink of wireless channel have also been studied, for example in [9,10,11]. Some studies investigated properties of homogeneous network environment [7,9,11,14,16,17] or mobility characteristics [13, 15].

However, research on the issue of bandwidth allocation for wireless IP networks up to now shows that the compensation in bandwidth allocation is not a completely considered. Compensation has been reviewed in several studies such as [2,19,20,6,8,10,12]. However, they are usually done by forcing the flow to give its bandwidth, even the flow needs the bandwidth. That means that services for other flows will be worse in case of compensation. Pre-preservation of a fixed bandwidth for compensation is not efficient due to waste of unused bandwidth.

Channel quality control, channel error detection, compensation adaptation to ensure the desired properties of a scheduling mechanism is content of next section.

3.2. Compensation mechanism to support bandwidth allocation in wireless networks

3.2.1. Monitoring wireless channel

Wireless channel experiences large variation due to many different factors such as noise, interference, fading, obstacles, and movement of the user. These factors may lead to channel errors (bad channel conditions) and the variation of wireless channel bandwidth. To compensate the bandwidth and guarantee QoS, it should monitor and detect the channel error. How to detect channel errors is the issue that should be further considered. This paper supposes that we can identify the time of channel errors and channel recovery time, thus we

concentrate on the mechanism of compensation in bandwidth allocation.

3.2.2. Bandwidth compensation model

In a fair scheduling mechanism, without channel error consideration, each flow i in a set of flow F is assigned a weight r_i . The incoming k^{th} packet of flow i (p_i^k) is assigned a starting label $S(p_i^k)$ and a finishing label $F(p_i^k)$, as follows:

$$S(p_i^k) = \max\{V(t(p_i^k)), S(p_i^{k-1}) + L_i^{k-1} / r_i\}$$

$$F(p_i^k) = S(p_i^k) + L_i^k / r_i$$

$$dV / dt = C(t) / \sum_{i \in B(t)} r_i$$

Here, L_i^k is the length of the k^{th} packet of flow i , $t(p_i^k)$ is incoming time of p_i^k , and $V(t)$ is a time function for the flow. $B(t)$ is set of flows having packet in queue at time t , $C(t)$ is channel capacity at t . At each timeslot, the scheduler needs to send the packet out of node. The packet with minimum finishing label is selected to send out. Thus, bandwidth allocated for flow i is directly proportional with time function $V(t)$. Figure 1 shows an example for two flow with equal weight $R_1=R_2$. During (t_1, t_2) , two flow are served proportional with its weight, in according to the time function $V(t)$ (Figure 1a).

Suppose in $[t_2, t_3)$, flow 2 is aware of channel error, thus it doesn't receive service. Flow 1 receives then all bandwidth during this time (Figure 1b). The raised demand is to give compensation to flow 2 so that after t_4 , two flows are fairly served.

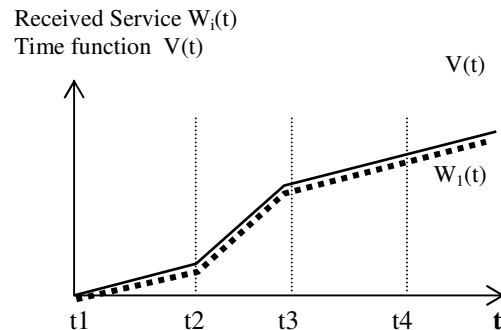


Figure 1a. Proportionality of received service $W_i(t)$ and the time function $V(t)$

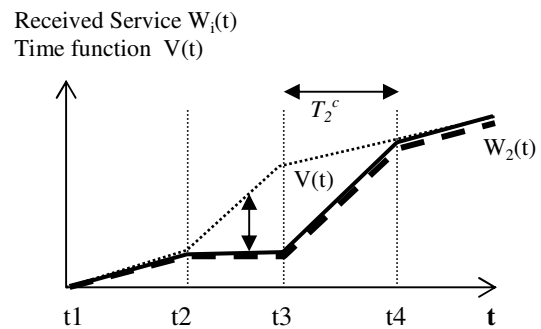


Figure 1b. Behavior in channel error.

A problem arises: where bandwidth for compensation is taken from and whether it affects other flows or not? There are two general ways to solve it: 1) Pre-reservation of a bandwidth for compensation, but this method is not effective due to waste of scarce wireless bandwidth; 2) To force other flows to give a partial bandwidth for compensation. This is the popular method. However, this method will affect the QoS of other flows.

In this paper, a new compensation model is proposed as follows:

We divide the incoming traffic into two set of flows: the set of flows with real-time requirements (QoS required) X and the set of flow without real-time requirements S . The bandwidth allocated for these sets are αC and βC respectively, where C is the total channel bandwidth, α and β are adjustable coefficients, and $(0 \leq \alpha, \beta < 1)$.

The condition for the stable bandwidth allocation mechanism is:

$$\alpha C + \beta C \leq C$$

If $\alpha C + \beta C > C$, bandwidth of channel is not enough to allocate and the scheduler can not guarantee service quality required by real-time applications. Scheduler can not accept any new flow.

A part of bandwidth βC will be used to compensate for flows with real-time requirements, which had channel error in the past. The scheduler provides this additional bandwidth by compensation using the weight r_i as follows:

$$R_i(t) = \begin{cases} R_i + r_i \\ R_i \end{cases}$$

The compensation factor r_i can be selected regarding the need of compensated flow. If r_i is large, the compensation time is quickly, and vice versa. Because the scheduler only uses partial bandwidth βC to compensate, so the real-time flows will not be affected.

When channel error of a real-time flow is detected, a register $M_i(t)$ is activated to record the amount of lost bits of the flow. $M_i(t)$ increases as follows:

$$\frac{dM_i(t)}{dt} = R_i * \frac{dV(t)}{dt}$$

When error channel is restored, flow i will be compensated by the weight $R_i + r_i$ during compensation time. The register of flow i will reduce as follows:

$$\frac{dM_i(t)}{dt} = -r_i * \frac{dV(t)}{dt} \quad (1)$$

Any flow i that has packet waiting in queue during $[t_1, t_2]$ is served in proportion with the time function $V(t)$. Amount of its received service $W_i(t_1, t_2)$ in this interval is:

$$W_i(t_1, t_2) = \begin{cases} (R_i + r_i) * (V(t_2) - V(t_1)) \\ R_i * (V(t_2) - V(t_1)) \end{cases}$$

Where the above value is for $M_i(t) > 0$ and the below value is for other cases.

The time of compensation completion is when the register reaches 0. The time interval from the beginning to the end of compensation is called the compensation time for the flow.

Figure 2 and 3 denote simulation results for our compensation mechanism in bandwidth allocation for wireless networks. There are three flows in the simulation with equal bandwidth requirements, i.e. they have equal weight in bandwidth allocation $R_1 = R_2 = R_3 = 0.2$. Flow 1 is error-prone during the time $(0.1 \text{ s}; 0.6 \text{ s})$. In this simulation, we suppose $\beta = 0$, i.e. all three flows are real time flows. The adjustable coefficient α is chosen as 4%, i.e. the maximum compensation scope for flow 1 is 4%. Choosing this value has great influence on the compensation time and rate. Method for selecting and the value of α are under further investigation.

If a traditional scheduler (such as WFQ) without compensation is used, flow 1 will lose service during $(0.1 \text{ s}; 0.6 \text{ s})$ due to channel error and never receives that service again when its channel is recovered at $t=0.6 \text{ s}$ (Figure 2).

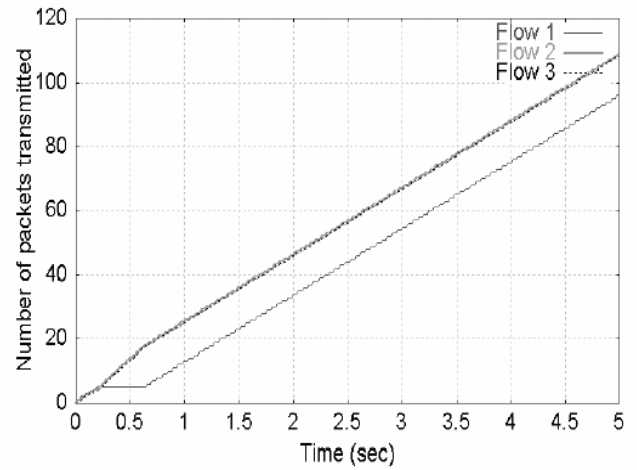


Figure 2. Operation of scheduler without compensation (such as WFQ)

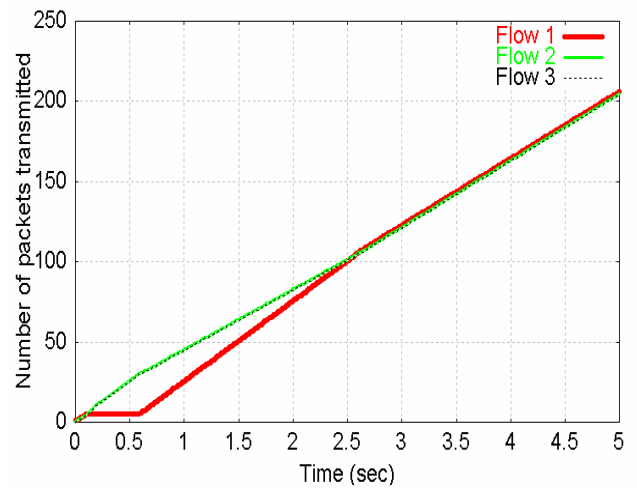


Figure 3. Operation of proposed compensation mechanism

If we use our compensation mechanism as presented above, flow 1 will be compensated when its channel is recovered (Figure 3). During compensation time, its register decreases according to the equation (1). The compensation will last until $t=2.6s$ (as long as the register value doesn't reach 0). Compensation time depends on the amount of lost service and the compensation factor. At the end of compensation, three flows are equal served again (from $t=2.6s$).

IV. IMPLEMENTATION DISCUSSION

As described above, channel supervision and exact detection of the channel error time and the recovery time are necessary for calculating the lost service of the flow. Based on this calculation, we can determine the amount of required bandwidth for flow compensation in order to guarantee the QoS of the flows, to maintain the fairness of the flows and to avoid the impact between them.

This paper presented a new compensation mechanism and the corresponding principle of bandwidth compensation, but there are still some open issues to investigate, namely:

- Method for channel error detection and determination of channel recovery time.
- Calculation of the values α and β to guarantee QoS of real-time flows, avoiding the interaction between flows, effective use of wireless bandwidth.
- Calculation of r_i , thus the compensation does not affect real-time flows, the compensation time is not too long by maintaining fairness during all the connection time and even in a short period.
- Determination of the acceptable level of fairness for the flows.
- Considering other factors, such as channel quality in the past, channel state forecast, etc.

These issues should be further studied by considering the heterogeneous environment of NGN network and the variety of applications.

V. CONCLUSION

This paper presented existing problems in bandwidth allocation in order to guarantee QoS, fairness of various applications in the converged network environment of the next generation network. The paper proposed a method for bandwidth compensation with respect to QoS guarantee and effective use of the limited wireless bandwidth, in order to ensure the fairness in bandwidth allocation. Simulation results have shown the feasibility of proposed mechanism.

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