Considerations for Bandwidth Adaptation Mechanisms in Wireless Networks

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***Abstract*— Bandwidth adaptation (BA) mechanisms provide an effective solution for handling congestion in wireless multimedia networks. Several factors go into the design of a bandwidth adaptation mechanism. In this paper, we investigate some of these factors and study their effect on the performance of bandwidth adaptation mechanisms. A simple model was proposed to help us with our study. Simulation results show that each of the studied factors can positively affect the performance of bandwidth adaptation mechanisms in certain scenarios.**

***Index Terms*—Bandwidth adaptation, congestion control, call degradation, wireless multimedia networks.**

I. Introduction

The demand for wireless networks to offer multimedia applications has been rapidly increasing over the last few years. Such demand growth raised the challenge of having heavily congested wireless networks that need to effectively serve users with good quality of service while minimizing operational costs. It hence became important to design congestion control mechanisms that can achieve this goal.

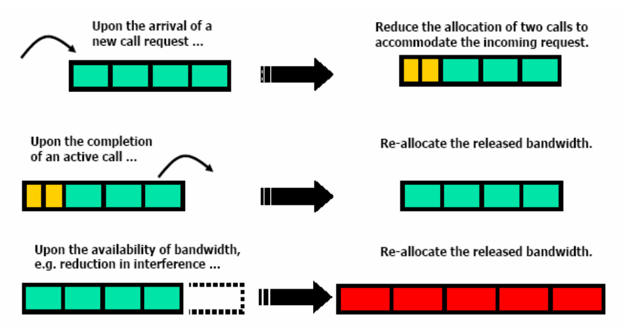

Fig. 1. Different BA Operation Scenarios [1]

Bandwidth adaptation (BA) mechanisms play an important role in controlling congestion in wireless multimedia networks. BA mechanisms take advantage of certain multimedia applications having flexible bandwidth requirements. In congested networks and upon the arrival of new or handoff call requests, a BA mechanism tries lowering (degrading) the bandwidth allocated to certain (or all) of active calls in order to "make room". Similarly, when bandwidth is made available due to ended calls or changes in network conditions, a BA mechanism tries if possible to increase (i.e. upgrade) the allocations of some (or all) active degraded calls. Fig. 1 illustrates the scenarios of BA operation.

Several BA mechanisms for wireless multimedia networks have been proposed in the literature. Adaptations are generally based on some characteristics (or metrics) of existing calls, channel condition, or status of the network. For example, the BA mechanism proposed in [2] adapts calls based on their priorities. In [3], adaptations are controlled by a level factor that ensures fairness between calls. Adaptations in [4] are done equally among all exiting calls. In [5], adaptations are optimized based on level of degradation (i.e. how many bandwidth allocations are taken) for existing calls. The mechanism in [6] utilizes utility functions to provide fair adaptations among different classes of calls. The mechanism in [7] combines between adaptation and preemption where lower priority classes have higher preemption probability while higher priority classes have higher adaptation probability. In [8], adaptations are done in a different flavor. Unlike other mechanisms, adaptations are triggered on probabilistic basis instead of being done for each change of call's state.

It is obvious that the adaptation operation of previous BA mechanisms is usually based on degradation level or call priority. However, there are some other metrics that can be considered in adaptations other than degradation level and call priorities. These metrics include the total adaptation done per existing call, and the remaining time of an existing call. For example, it can be advantageous in some scenarios to adapt a call that is about to leave soon than adapting a newly arrived call. Investigating the performance effects of such metrics on BA mechanism might be useful to discover, or implement better adaptations mechanisms in term of processing power or call handling. In this paper, we investigate the effects of some call-related metrics on adaptation performance.

The remainder of this paper is organized as follows. Section II provides a brief overview of considerations when designing a bandwidth adaptation mechanism. Section III introduces the adaptation design metrics that have been studied in this paper. Section IV explains the system model used to study the effect of those metrics. Performance evaluation of the studied metrics is presented in section V. Finally, Section VI concludes the paper.

II. Designing Considerations of a Bandwidth Adaptation Mechanism

A. Definitions for Classes of Services

Wireless networks offer different types of applications.

Each application has its characteristics and minimum requirements. The design of a bandwidth adaptation mechanism must hence take into consideration the definition of different classes to be served in the network.

A class of service is commonly characterized by a set of bandwidth allocations, Ω, where $\Omega = \{\omega_1, \omega_2, \ldots \omega_i \ldots, \omega_N\}$ with N being the number of possible bandwidth allocations for the service. The allocations defined of the set are ordered such that $\omega_i < \omega_{i+1}$. ω_1 must be at least a value that guarantees the minimum level of service specified for certain class, while ω_N must be the maximum sufficient value for that class. For each class, there must be a reference allocation ω_{ref} that belongs to the set of allocations Ω. The ω_{ref} is defined to be the target allocation for all calls of that class. The value of ω_{ref} can be any value in the set. When an active call is given an allocation less than ω_{ref}, the call is said to be downgraded. On the other hand, when an active call is given an allocation greater than ω_{ref}, the call is said to be upgraded [1].

B. Required Metrics

A BA mechanism needs to know how much that it can downgrade or upgrade a call or a certain class of calls, and when to do such downgrade or upgrade. Based on the classes' definition in the network, whenever the adaptation mechanism is to be engaged, the system needs to compute how much of the allocated bandwidth is either degradable or upgradeable.

The choice of required metrics for a BA mechanism's decision making is not simple. It depends on class of services' definitions and network's requirements. Some metrics can be insufficient for the mechanism to efficiently operate. For example, measuring how much a certain class can be degraded or upgraded can make the adaptation mechanism to persistently degrade that class for long time. Therefore, the use of different metrics regarding different classes must be considered.

In general, the required metrics must be selected so the classes are protected from persisted downgrading while having efficient downgrading and upgrading among all classes. That will help in reducing the effect of fluctuations on measurements and thus on the number of adaptations required.

III. Metrics Affecting Bandwidth Adaptation Mechanisms

We identify two types of metrics affecting BA algorithms. One related to classes of service and the other related to required measurements.

A. Related to the Definitions for Classes of Services

1) Class of Services Priority (CP): Depending on operation requirements, calls can be classified according to their importance (e.g. premium, real-time, critical, etc.). The goal for considering such a factor is to provide better bandwidth services for higher classes while utilizing the advantages of adaptation mechanisms.

2) Degrading Difference Threshold (DDT): This factor presents the maximum degrading difference that can exist between any two calls within a same class of service. The goal of this factor is to provide fairness between degraded calls within a same class. However, this factor requires to do more measurements in order to know what the minimum degraded call is.

3) Degrading (DT) and Upgrading (UT) Thresholds: These factors present the maximum adaptations that can be made per call per adaptation step. Usually lower values can provide better fairness among existing calls within same class for heavily congested networks.

B. Related to Required Measurements

1) Call's Current Degradation Amount (DA): When this measurement is considered, the less degraded call will be considered first for degrading.

2) Call's Remaining Time (CRD): When this measurement is considered, a nearly departed call will be considered for degrading before new or long ones.

3) Call's Total Adaptation (TA): When this measurement is considered, the call with least number of bandwidth adaptations occurred will be considered first for degrading.

IV. System Model

In order to simplify our study, we assume the following:

- New calls start with their maximum possible bandwidth allocation. The system either provides this allocation or rejects the new call
- Considerations related to channel medium or protocol specific such as bit error rate (BER) can be met and need not be explicitly considered.
- None of the existing calls will be dropped.
- Existing calls will maintain at least a minimum guaranteed bandwidth allocation.

Based on these assumptions, we propose a simple model for bandwidth adaptation based on the following scenarios:

1) Adaptation mechanism is inactive: In this case, the new calls are blocked if there is no available bandwidth.

2) Adaptation mechanism is active with FCFS adaptation handling: When a new call arrives, the degrading process is engaged for existing calls pool in the order they arrive to the system. Then any degraded call will be moved to the end of the pool so it is not considered again until all other existing calls are considered for degrading. The upgrading process has the similar fashion. If there is no enough bandwidth collected by the degrading process, the new call is rejected.

3) Adaptation mechanism is active and adaptation handling based on multiple FCFS call pools with calls inserted based on their DP value: Existing calls are sorted into multiple pools based on each call's *Degradation Priority* (*DP*). The *DP* value is calculated according to the algorithm presented in Table 1.

TABLE I. ALGORITHM FOR CALCULATING *DP*

Calculation of *DP*

/* *ACD* is the average call duration for departed calls from same class so far

ET is the call's elapsed time

NPools is the number of pools used by the mechanism*/

N = 0
D = 0
IF (*DAFactor*>0)
THEN

$$N = N + DAFactor \cdot (\frac{DA}{MaxDa})$$

$D = D + DAFactor$

IF (*CPFactor*>0)
THEN

$$N = N + CPFactor \cdot (\frac{1}{CP})$$

$D = D + CPFactor$

IF (*CRDFactor*>0)
THEN

$$N = N + \begin{Bmatrix} \frac{CRD}{CRD+ET} & ,\text{known Duration} \\ Max(0, \frac{ACD-ET}{ACD}) & ,\text{Unknown Duration} \end{Bmatrix}$$

$D = D + CRDFactor$

IF (*TAFactor*>0)
THEN

$$N = N + TAFactor \cdot (1 - \frac{1}{\log(TA + e)})$$

$D = D + TAFactor$

IF (D>0)
THEN

$$DP = NPools \cdot \frac{N}{D}$$

ELSE

$DP = 0$

END

In the degrading process, the first call inside the pool with lowest *DP* is considered first to be degraded. In the upgrading process, the first call inside a pool with highest *DP* will be considered first to be upgraded. When a call's *DP* value is changed, the mechanism reallocates it to the end of corresponding pool.

V. PERFORMANCE EVALUATION

Different simulation experiments are carried out to investigate the effect of studied metrics on the adaptation performance as shown in following subsections.

A. Effect of DA, CRD and TA

In this experiment, a simulation was setup to compare between the following scenarios:

- Adaptation being disabled (*NoBAA)*
- Adaptation being enabled in FCFS manner (*NoSorting*)
- Adaptation depends on *DA*
- Adaptation depends on *CRD*
- Adaptation depends on *TA*

The simulation environment consists of single class with maximum available bandwidth of 110592Kb. This class has Ω = {64, 80, 128, 160, 256, 384, 512} Kb. Arrived calls are exponentially distributed with mean of 60 sec. The values of *DT* and *UT* were set to 1, and the effect of *DDT* is ignored.

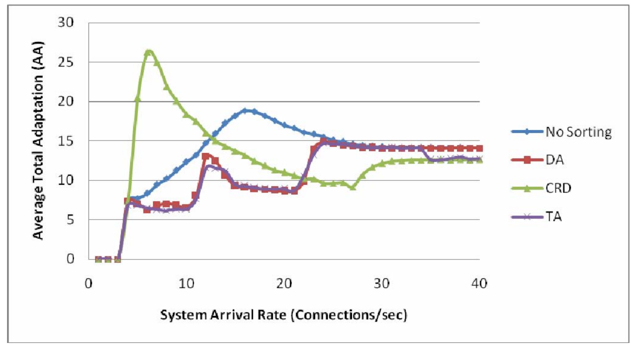

Fig. 2. Average Adaptations per call for different scenarios

Fig. 2 shows the effect of different metrics on the adaptation performance. For very lightly congested systems, it is found that both mechanisms that based on *DA* and *TA* are outperforming. With *DA* or *TA*, any degraded call for a lightly congested system will be moved to the end of pool and let other existing calls to be degraded. Thus, *DA* and *TA* mechanisms will provide fairness among all existing calls without having too many adaptations. As the system becomes highly congested, the mechanisms based on *CRD* and *TA* becomes more effective to reduce the fluctuations on adaptation process.

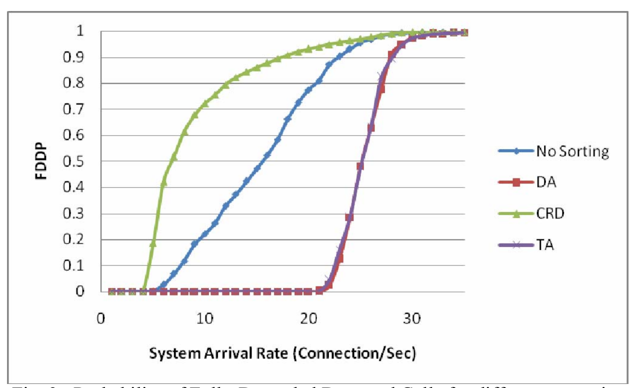

Fig. 3. Probability of Fully-Degraded Departed Calls for different scenarios

Fig. 3 shows the effect of different metrics on the probability of fully-degraded departed calls. As in Fig .2, scenarios based on *DA* or *TA* are still outperforming in term of having less fully-degraded departed calls. The scenario based on *CRD* performs worst since the degrading is based proportionally on the remaining time of a call, and thus the possibility for this call to be persisted-degraded before departure is high.

B. Effect of Degradation Difference Threshold

Figs 4, 5 and 6 show the effect of three different *DDT* values on the performance of FCFS adaptation mechanism. A lower *DDT* value helps providing a better average degradation and fairness. On the other hand, lower values of *DDT* get higher blocking probability. In addition, having too high *DDT* value can make calls suffer from high bandwidth adaptations. Thus a good *DDT* value should balance between fairness, blocking probability and adaptations.

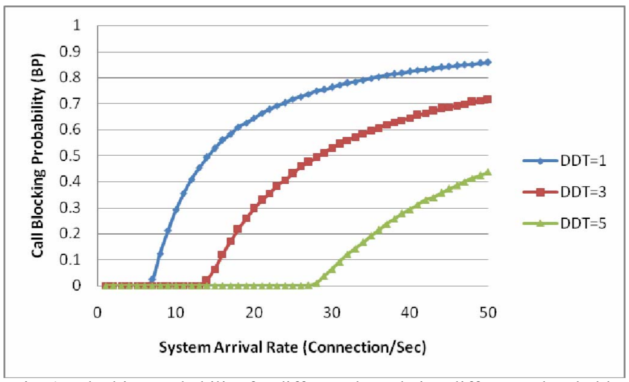

Fig. 4. Blocking Probability for different degradation difference thresholds

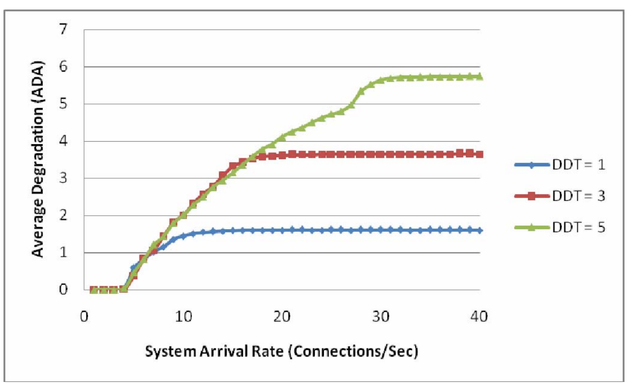

Fig. 5. Average Degradation Amount for different degradation difference thresholds

C. Effect of Degrading and Upgrading Thresholds

Fig. 7 show the effect of three different *DT* and *UT* values on the performance of FCFS adaptation mechanism. As the allowed number of bandwidth allocations per call during one adaptation step increases, the average total number of adaptations per call's lifetime decreases. However, high *DT* can make some calls suffer from unfair degradation.

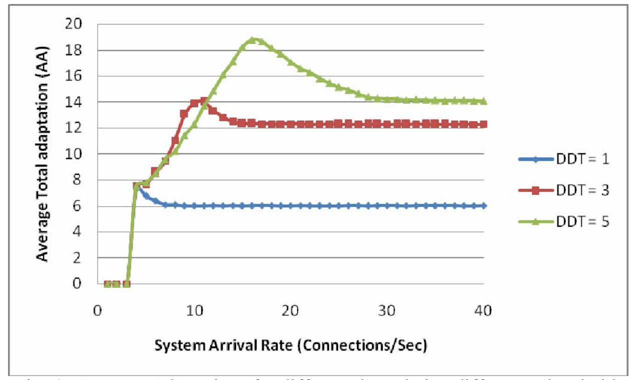

Fig. 6. Average Adaptations for different degradation difference thresholds

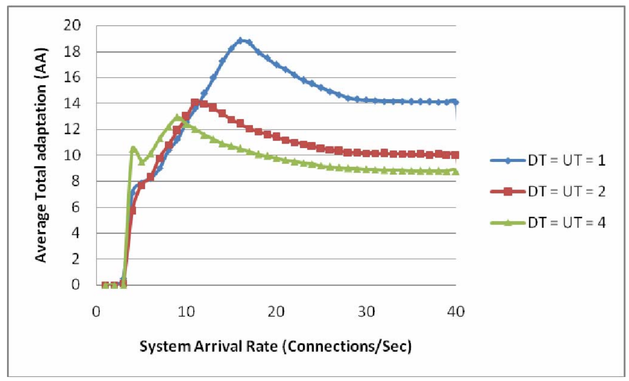

Fig. 7. Average Adaptations for different *DT* and *UT*

D. Effect of Class Priority

In order to study the effect of the class priority, another simulation was setup with maximum available bandwidth of 49152Kb, and three classes where each class has $\Omega = \{64, 80,128,160,256,384,512\}$ Kb. Arrived calls are exponentially distributed with mean of 60 sec, and half of these calls have unknown duration. The values of *DT* and *UT* were set to 1, and the effect of *DDT* is ignored.

Figs 8 and 9 show the effect of having class priorities on adaptations done to different classes. Clearly, the class with highest priority (*CP* = 1) has better average degradation. On the other hand, the calls of that class will suffer from high adaptations while the calls of other lower priority classes will suffer from persisted degradations.

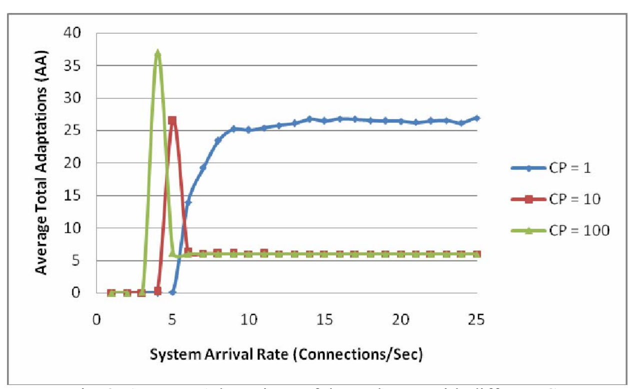

Fig. 8. Average Adaptations of three classes with different CP

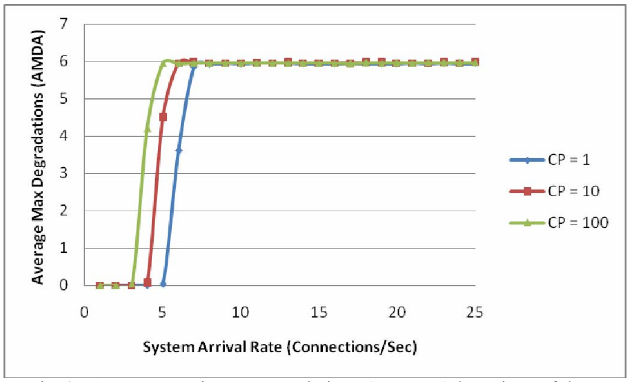

Fig. 9. Average Maximum Degradations Average Adaptations of three classes with different CP

VI. CONCLUSION

Some factors that go into the design of a bandwidth adaptation mechanism were studied in this paper. Studies show that each factor can suit certain scenarios. In addition, carefully choosing the values for some or all of these factors can enhance the general operation of adaptation mechanisms.

However, more investigations are required to explore the effects of additional factors on the performance of a bandwidth adaptation mechanism. The selection of the good values for these designing factors needs also further exploration.

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