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QoS Provisioning of QoS in Wireless Networks carrying multimedia traffic

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***Abstract*— The provisioning of QoS in wireless networks carrying multimedia traffic imposes a big challenge to network designers and traffic engineers. Guaranteeing QoS in wireless networks is a complicated task due to the unique characteristics of wireless networks such as user mobility, limited link capacity, and frequent link failure, scarcity of bandwidth, channel fading, and inability to predict the availability of resources in the network. Multimedia applications (audio phone, video on demand, video conference, files transfer, etc.) will be integrated into future mobile communication systems. Although the QoS provisioning problem arises in wireless networks as well, mobility of hosts, scarcity of bandwidth, and channel fading make QoS to transient fluctuations in the QoS that they receive from the networks. Bandwidth is the most critical resource in mobile multimedia wireless networks. Due to mobile user mobility and limited bandwidth in the mobile wireless communications networks, the quality-of-service (QoS) guarantee becomes very complicated for multimedia applications.**

***Keywords* – WLAN and cellular network integration, IEEE 802.11, Quality of Service (QoS) provisioning, Call admission control(CAC), Channel fading, Bandwidth reconfiguration, Mobility, Handoff management, Bandwidth borrowing , Mobile host.**

I. INTRODUCTION

The rapid growth in interactive multimedia applications, such as audio phone, video on demand, video conference and video games has resulted in spectacular strides in the progress of wireless communication systems. Multimedia applications make a great demand for bandwidth and should be transmitted continuously. Since bandwidth is the most critical resource in mobile multimedia wireless networks, it is important to employ mechanisms for efficiently using the available bandwidth. In mobile cellular communication networks carrying multimedia traffic, it becomes necessary to provide quality-of-service (QoS) guarantees for multimedia traffic connections. These networks have the inherent problem of rapid handoffs due to smaller coverage areas of base stations. This problem leads to higher connection dropping probability and results in bandwidth resource availability varying repeatedly. Frequent changes in the network traffic make the provision of guaranteed QoS more difficult. Hence, research in the area of QoS provisioning in the next-generation high-speed wireless networks focuses on the integration of resource allocation and admission control policies [11]. Recently, several bandwidth allocation schemes have been proposed to support QoS provisioning in wireless environments. A rate-based borrowing scheme for QoS provisioning in multimedia wireless networks is proposed in to provide network users with QoS in terms of guaranteed bandwidth, connection-blocking probability (CBP), and connection-dropping probability (CDP) by using bandwidth borrowing. In [11], based on the maximum fairness allocation protocol, a fair resource allocation protocol for multimedia wireless networks is proposed to improve connection-blocking probability, connection- dropping probability, and bandwidth utilization.

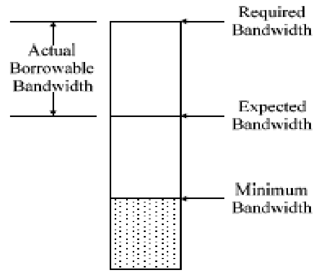

Figure 1: Bandwidth requirements of a connection for Class I and II

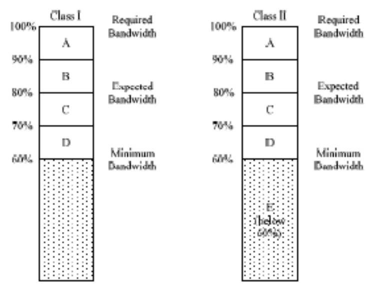

Figure 2: Satisfying degree of QoS connections

This paper introduces a novel bandwidth borrowing scheme that supports QoS guarantees in the next generation mobile multimedia wireless networks. In the proposed scheme, we classify all multimedia traffic into (1.) real-time (Class I) and (2.) nonreal-time (Class II) traffic. Real-time traffic includes voice and video while data and graphics make up nonreal-time traffic. Also, we provide the efficient bandwidth re-distribution approach in a base station by using the attribute of multimedia traffic. In order to evaluate the overhead of bandwidth reconfiguration and satisfying degree of QoS of ongoing MHs in cellular systems, new measurement method is proposed in this paper.

II. 2. Resource Management in Wireless Networks

The role of wireless networks resource management is to provide QoS guarantees to multimedia traffic according to their bandwidth requirements while maintaining the high utilization of network resource. The resource management in wireless networks can be implemented in two levels:

• Macro-level, which involves call admission control (CAC), resource allocation and resource reservation etc. to control the connectivity and end-user's perceived QoS of the applications.

• Micro-level, which deals with power control, media access control (MAC) and packet scheduling etc. to control the QoS parameters such as delay and jitter of the applications.

This paper focuses on the macro-level resource management in multimedia wireless networks. According to no matter which multiple access technology (FDMA, TDMA or CDMA) is used, the network capacity can be interpreted in terms of bandwidth. In other words, bandwidth is the only resource under consideration in multimedia wireless networks. To avoid the complexity of central coordination, resource management is performed based on each individual BS (cell) of the network in a distributed manner. In each BS three resource management functionalities including CAC, bandwidth allocation and bandwidth reservation, cooperate with each other to provide integrated QoS guarantees to multimedia traffic.

2.1 CALL ADMISSION CONTROL (CAC)

CAC is one of the most important bandwidth management components in wireless networks. The objective of CAC is to provide QoS guarantees for the calls which request access to the network while efficiently utilizing network bandwidth. Since wireless networks are characterized by user mobility, CAC is invoked not only when the new calls initially enter the network, but also whenever the ongoing calls hand off from one cell to another. When a new or handoff call arrives, CAC first checks the network bandwidth availability. If the available bandwidth of the network can satisfy the requested bandwidth of the new or handoff call, the call is accepted; otherwise, the call is rejected. Rejecting a new call request leads to call blocking at service initiation and rejecting a handoff call request leads to call dropping in the middle of service. Hence a good CAC algorithm is very important for wireless networks and it directly affects the QoS of new and handoff calls.

2.2 BANDWIDTH ALLOCATION IN WIRELESS NETWORKS

Bandwidth is an extremely valuable and scarce resource and it should be used in the most efficient manner. The role of bandwidth allocation is to decide how the bandwidth is shared among all ongoing calls in the network in order to satisfy the different QoS requirements. The bandwidth allocation can be divided into two categories: non-adaptive bandwidth allocation and adaptive bandwidth allocation. With non-adaptive bandwidth allocation, once a call is admitted a contract between the network and the call is established. Then, they both try to keep the contract throughout the lifetime of the call. When a new or handoff call requests a certain amount of bandwidth, the network rejects the call if there is not sufficient bandwidth available. On the other hand, when an ongoing call is terminated due to its completion or outgoing handoff, the released bandwidth cannot be utilized to upgrade other ongoing calls.

2.3 BANDWIDTH RESERVATION

Unlike wireline networks with stationary users, wireless networks are characterized by user mobility. After a call is handed off from the original cell to the destination cell, to support the continuity of the service the destination cell needs to allocate some bandwidth to the call. If the destination cell does not have enough bandwidth, the handoff call request will be rejected. In the network, new calls and handoff calls are competing for the usage of the finite bandwidth resource. Generally, the blocking of new calls and the dropping of handoff calls cannot be reduced simultaneously; it is a matter of tradeoffs. It is widely accepted that from the end-users' point of view the dropping of a handoff call is much more Unbearable than the blocking of a new call. To protect handoff calls from being dropped, the network can give them higher priority over new calls by reserving some bandwidth for their exclusive use. Bandwidth reservation is either static or dynamic. Static approach reserves a fixed percentage of bandwidth in each cell of the network. When a handoff call arrives to an overloaded cell, the reserved bandwidth can be used to support the handoff call. The advantage of static reservation is that no communications between cells are needed thus it is very attractive in practical implementation.

III. 3. QoS IN MULTIMEDIA WIRELESS NETWORKS

3.1 CHALLENGES OF QOS PROVISIONING

Wireless networks provide more freedom to communications than wire line networks. However, the distinctive characteristics of wireless networks present great challenges to the QoS provisioning for multimedia traffic.

3.1.1 BANDWIDTH LIMITATION

The link bandwidth of wireless networks is much scarcer than that of wire line networks. In the past few years, with the presence of more portable devices coupled with the easy access to wireless networks, the number of mobile users has increased massively. Meanwhile, new wireless applications especially bandwidth-intensive multimedia applications (e.g. video on demand) are emerging. All these have greatly increased the bandwidth demand in wireless networks. Even though rapid progress is being made for high-speed wireless communications, such as the introduction of 3G and WLAN, bandwidth is still the major bottleneck in wireless networks due to the physical limitation of wireless media.

3.1.2 HANDOFF MANAGEMENT

The bandwidth availability in wireless networks is highly variable due to channel fading and user mobility. Channel fading is the time variation of received signal power caused by changes in the transmission medium or paths, and user mobility means the roaming of mobile user across the cell's coverage area. Although the effect of channel fading can be mitigated by rich-function transmission/reception wireless subsystems, user mobility may cause severe bandwidth fluctuations in wireless networks. For instance, a call may be admitted into the network in a cell where its requested bandwidth can be easily met, but during the calls' lifetime it may be handed off to another cell with insufficient bandwidth. Since the user's itinerary and the bandwidth availability in various cells are usually unknown in advance, global QoS guarantees are very hard to provide. The problem becomes even more challenging as recent wireless networks have been implemented based on small-size cells (i.e. microcells and picocells) to allow higher transmission capacity, and thus to accommodate more mobile users. Small-size cells increase the handoff rate and result in rapid changes in network conditions, making handoff management difficult.

3.2 MEASUREMENTS OF QOS

According to the QoS in multimedia wireless networks can be measured at two abstraction levels, i.e. connection-level QoS and packet-level QoS.

3.2.1 CONNECTION-LEVEL QOS

Connection-level QoS is the basic level QoS in wireless networks. It is related to connection establishment and management, which are very important in wireless networks, especially in dealing with handoff requests generated by user mobility. Connection-level QoS measures the connectivity and continuity of services, mainly in terms of two parameters, i.e. calls blocking probability and handoff dropping probability. Call blocking probability is the ratio of the number of blocked new call requests due to insufficient bandwidth, to the total number of the new call requests initiated within the cell; it measures service connectivity in the present of new call requests. Handoff dropping probability is the ratio of the number of dropped handoff call requests due to insufficient bandwidth to the total number of handoff call requests roaming into that cell; it measures service continuity during handoff.

3.2.2 APPLICATION-LEVEL QOS

Connection-level QoS is necessary for wireless networks, but it is usually not enough, especially in assessing the applications qualities perceived by end-users, whose services has been connected and continued by the connection-level QoS support functions. Application-level QoS is introduced as a supplement to connection-level QoS and it refers to the applications qualities that the network offers to end-users in terms of QoS parameters including bandwidth, delay/delay variation, and loss/error rate, etc. The work presented in this thesis uses utility to evaluate application-level QoS. Utility was originally introduced in the research of economics and has been used as the QoS measurement in both wireline in recent years. Utility represents the “level of satisfaction” of an end-user or the performance of an application. Generally, the utility of an application is a function of its bandwidth, delay and loss performance over the network. But it is reasonable to assume that the application’s delay/loss requirements are independent of its actual allocated bandwidth. Then utility will depend only on the available bandwidth that the network can allocate to the application while meeting its delay/loss requirements.

3.3 PREVIOUS WORK ON QOS PROVISIONING

In the past few years, QoS provisioning in wireless networks have attracted the interests of many researchers. An adaptive bandwidth reservation scheme to provide QoS guarantees for multimedia traffic in wireless networks. The scheme allocates bandwidth to a call in the cell where the call request originates and reserves bandwidth dynamically in all neighboring cells according to the network conditions. Bandwidth reservation in all neighboring cells guarantees the QoS of handoff calls, but it often results in the underutilization of network resource as mobile user hands off to only one of the cells. Bandwidth allocation scheme for QoS support in broadband wireless networks consisting of three service classes with different handoff dropping requirements. The scheme includes the measurement-based CAC and bandwidth reservation algorithms to adaptively allocate bandwidth to the calls so that the target handoff dropping probability can be met. The main disadvantage of the scheme is that the allocated bandwidth of the call is kept fixed during the stay in the cell and it can only be changed when handoff happens. An adaptive bandwidth allocation framework which can adjust the bandwidth of ongoing calls during their stay in the cell whenever there are resource fluctuations in wireless networks. When a new or handoff call arrives to an overloaded network, the bandwidth adaptation algorithm can reduce the allocated bandwidth of ongoing calls to free some bandwidth for the new or handoff call. The bandwidth adaptation algorithm minimizes the number of calls receiving lower bandwidth than that requested. In bandwidth adaptation scheme is developed for wireless networks to guarantee the upper bound of the call degradation probability. To reduce handoff dropping probability, a fixed amount of bandwidth is reserved for handoff calls in each cell. The scheme makes adaptive decisions for bandwidth allocation by employing attribute-measurement mechanism and service-based bandwidth borrowing policy. A dynamic time interval reservation strategy is introduced to provide QoS guarantees for handoff calls by adjusting the amount of reserved bandwidth in each cell according to the online traffic information. Compared to the bandwidth adaptation schemes proposed in provide more flexibility in bandwidth allocation since they can change the bandwidth of ongoing calls during their stay in the cell. However, these schemes have one common drawback, i.e. they have not provided any mechanism to measure the degradation of calls.

IV. STATE OF THE ART

The channel borrowing algorithms can be divided into simple and hybrid [2]. In simple channel borrowing algorithms, any nominal channel in a cell can be borrowed by a neighboring cell for temporary use. In hybrid channel borrowing strategies, the set of channels assigned to each cell is divided into two subsets: (1) local and (2) borrowable. The local subset is used only in the nominally assigned cell, while the borrowable subset is allowed to be lent to neighboring cells. The suggested algorithm belongs to the simple channel borrowing algorithms. A comprehensive survey of the channel borrowing algorithms is presented in [3]. A number of simple channel borrowing algorithms have been presented in the literature.

4.1 QOS-BASED CHANNEL BORROWING ALGORITHM

As opposed to the Borrow from the richest [3],[7] algorithm, the suggested algorithm takes into account the effect of channel locking when choosing a candidate channel for borrowing. Furthermore, the suggested algorithm takes into account not only the number of available channels but also the average QoS level of each candidate cell. This allows the algorithm to try to maximize the average QoS level of the calls existing in the system in addition to minimizing the call blocking probability. The algorithm consists of three main modules: Algorithm modules I and II in addition to the channel borrowing module III. The reason behind using modules I and II is to divide the problem into smaller easier to handle sub-tasks since the search space is too large for a single A. Module I assigns fair bandwidth allocations to the existing calls; whereas module II maximizes the capacity utilization by assigning any available bandwidth (left over from module I allocations) to the existing calls. Eventually, the system will not force a call to drop unless there is not enough bandwidth to satisfy its minQ level. Module III is added as an important enhancement layer to allow for channel borrowing to take place in such an adaptive QoS environment. Module I is triggered whenever a call arrival or departure takes place. The inputs to module I include: (1) the capacity of the system (physical cell capacity), (2) the number of calls (N) after the arrival/departure and (3) the bandwidth information for these calls and their preset UDPs (which are fetched from the database). Furthermore, QoS levels from the previous allocation are also fed back to module I. Module I search for the QoS levels that correspond to the bandwidth allocation closest to the "fair" bandwidth. The evaluation of the optimization function is based upon the following rules:

$$B_{fair} = C_{tot} / N \qquad (1)$$

Where
B_{fair} is the fair bandwidth Allocation, and
C_{tot} is the total physical cell capacity.

In Eq.3, the calculation of the fair bandwidth is applicable to calls of similar classes (i.e., having the same type of multimedia substreams) for each of the existing call, the following equations are applied:

$$B_{modI}(i) \in B_i(Q_i) \qquad (2)$$
$$B_{modI}(i) = \text{minimum}(\text{absolute}(B_{fair} - B_i(Q_i))) \qquad (3)$$
$$B_{modI}(i) \le B_{fair} \qquad (4)$$

Where
i is the call number,
$B_{modI}(i)$ is the bandwidth requirement corresponding to the output QoS level from module 1,
$B_i(Q_i)$ is the bandwidth requirement corresponding to the QoS level Q_i, and
B_{fair} is the fair bandwidth.

Once the fair allocations are determined by module I, if any of the assigned QoS levels in module1 is less than the corresponding minimum QoS level minQ, then this minQ level is assigned to the corresponding call. Then this data is sent to the module chooser for further processing. It starts by calculating the total bandwidth needed by all existing calls if granted the QoS levels assigned by module1. If the total bandwidth exceeds the cell capacity, then module III is triggered to try to borrow some bandwidth from the neighboring cell. Otherwise, module II is triggered to try to take advantage of any bandwidth left over from module I. Module II, on the other hand, is designed to take advantage of any available bandwidth left over from module I. It tries to maximize the link capacity utilization and thus maximizing the QoS levels for the calls In the following section, we are going to describe module III (channel borrowing algorithm) in more details.

4.2 MODULE III CHANNEL BORROWING ALGORITHMS

Throughout the description of module III, The cell layout is a seven-cell cluster surrounded by a second tier of 11 cells. The total number of cells in this two-tier layout is cells. The cell reuse plan is N=7. Each color in Fig. 7 represents a distinctive set of channel frequencies. The reason for choosing this specific layout is that module III is going to consider the first two tiers of the neighboring cells only. Cell A is the acceptor cell. It is surrounded by two tiers of cells. Cell A can borrow from any of its first tier neighbors (cell 1, cell 2… and cell 6). Furthermore, it can borrow channels from one and only one neighbor (no multiple donor cells are allowed). Borrowing any number of channels from any of these 6 cells will cause these channels to be locked in another two cells. To illustrate the concept of channel locking, let us assume that cell A is going to choose to borrow a number of free channels from cell 2. This will cause these borrowed channels to be locked in both cells 14 and 17. For this cell layout (N=7), the number of cells affected by channel locking is always 2 cells. We are going to denote these 2 cells as affected_cell1 and affected_cell2. In the suggested channel borrowing algorithm, each cell is required to keep track of the following parameters: (1) The number of available free channels if the existing calls are assigned their minQ levels, (2) the number of available free channels in affected_cell1 if the existing calls are assigned their minQ levels and (3) the number of available free channels in affected_cell2 if the existing calls are assigned their minQ levels. The information regarding the available number of channels in the affected_cell can be collected either periodically or on a need basis (a message sent from the cell to the affected_cell requesting immediate information regarding the number of available free channels).

Assuming that Cell A (the acceptor cell) needs N_b number of channels to borrow. The number of channels needed (N_b) should be calculated from the following equation.

$$N_b = (B_{tot} - C_{tot})/ Ch_{size} \qquad (5)$$

Where

B_{tot} Total bandwidth needed by existing calls if assigned their minQ level.

C_{tot} Total physical cell capacity

Ch_{size} size of each channel

Cell A will then send a borrow_request message to each of its first tier neighbor cells. Each of the neighboring cells receiving the borrow_request message will calculate the number of available channels (N_{av}) if its calls are granted their minQ level and compare it to the requested number of channels (N_b). If $N_{av} < N_b$, then the cell will send back a negative acknowledge (NACK) message informing the acceptor of the denial of its request. Otherwise, it will send a message to each of the affected cells (due to channel locking) requesting information regarding the number of available channels (N_{av} (affected_cell)). The information regarding the available channels does not have to be gathered when the borrow_request message is received. As mentioned before, this information can be gathered periodically and kept ready for any borrow_request message. If the returned values N_{av} (affected_cell) > N_b then this means that the requested number of channels is available for borrowing and that the locked channels (in the affected_cells) are also available. An acknowledgement (ACK) message is then sent back to the acceptor cell. Otherwise, a NACK message is sent back to the acceptor cell denoting that the locked channels will cause some calls to be dropped in the affected_cell. Fig. 8 (b) shows the flow of the messages if there are enough available channels in the neighboring (candidate) cell ($N_{av} > N_b$). If the affected cells return an ACK message, this implies that the locked channels due to the borrowing process will not cause any calls to be dropped in these cells. This is due to the fact that when the candidate cell sends a check_no_channel message to any of the affected cells; it will calculate the number of available channels after assigning the minQ levels to the calls existing in this cell. Therefore, immediately afterwards, the candidate cell send an ACK message to the acceptor cell informing it that it can fulfill the borrow_request message. The candidate cell will then wait for each of the affected cells to send message carrying information regarding the average QoS (average_qos) levels of the existing calls and the number of channels that would be available if the borrowing process is executed (N_{av}). The average_qos is calculated assuming the borrowing process has been executed. This will give an indication of how the borrowing process affects the QoS levels of the existing calls. In the meantime, the candidate cell will calculate the average QoS levels of its existing calls based on the same criteria. Notice that the candidate cell can calculate the average QoS level while the other affected cells are doing the same thing in parallel. Once all the information is available for the candidate cell, it will send it in a message to the acceptor cell.

(a) $N_{av} < N_b$,
(b) $N_{av} > N_b$

Once all messages from all the neighboring (candidate) cells are received, the acceptor cell will start processing the information searching for the best candidate cell to become the donor. First, all cells sending back NACK messages are removed from the candidate list. The information of each of the remaining cells in the candidate list include: (1) a vector of average QoS levels of the candidate cell, affected cell 1 and affected cell 2 (average_qos[]), and (2) a vector of available number of channels (N_{av}). The acceptor cell will use the following equation to calculate the cost of borrowing the requested number of channels from each cell. The cost value of each cell in the current candidate list is denoted by borrow_cost.

$$\text{borrow\_cost t} = \left[\frac{\min (N_{av})}{\text{max\_channels}} - \frac{\min (\text{average\_qos})}{64} \right] \quad (8)$$

Where (max_channels) is the maximum number of channels in each of the cells. Note that the value of average_qos ranges from 1 to 64 (1 being the best QoS level, and 64 being the least). Therefore, the value of borrow_cost ranges from -1 to 1. The higher the borrow_cost value, the better is the candidate cell. Therefore, the acceptor cell will choose the one with the highest borrow_cost value.

V. CONCLUSION

In this paper we presented an adaptive algorithm for channel borrowing in wireless cellular networks. The algorithm utilizes to optimize the network resources while maintaining the quality of service requirements of the users. This is achieved by 1) adopting a dynamic range of QoS levels that are acceptable to the user, 2) increase the efficiency of the network by allocating to the users an amount of bandwidth that is just enough to satisfy the users" minimum QoS requirements, 3) adaptively borrow the channels available from neighboring cells where capacity is available to cells where capacity is needed to meet traffic demands. The algorithm is adaptive in the sense that it re-allocates the channels allocated to different cells based upon the dynamic traffic pattern demands from the users. Hence, in hot cells, channels are borrowed to meet increasing demands for capacity and decrease calls blocking probabilities. The channel borrowing algorithm is essentially a multi-objective optimization function that tries to re-allocate channels to cells in order to minimize the call blocking probability, while in the mean time maintaining the QoS requirements of each call above a minimum contracted level. The several advantages of the proposed channel borrowing algorithm:
1) The network efficiency is increased as more calls can be accepted for the same amount of resources at a certain call blocking probability,
2) The quality of service provided by the network is enhanced as the call blocking probability is decreased for the same offered traffic loads, and finally
3) The QoS levels provided to the accepted calls are also enhanced.

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