Admission Control in Cellular Radio Systems
Based on Relative Load Estimates

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Abstract

When operating a cellular radio system nearly at full capacity, admitting yet another user may jeopardize the stability of the system as well as the performance of the individual users. Therefore, proper admission control is crucial. The core idea in this work is to predict the relative load of the system, given that a user is admitted. Then, the user will be admitted if the predicted load in the specific cell, and in its neighbors, is below some threshold. This provide an interesting alternative to algorithms based on hard capacity, which might be utilizing the resources inefficiently in order to be robust. The proposed uplink admission control algorithm utilizes measurements readily available in the system. Simulations indicate performance improvements. Furthermore, multi-services are naturally handled, and availability of high data-rate services are automatically limited with respect to coverage, compared to services of lower data-rate.

Keywords: cellular radio systems, admission control, WCDMA, uplink, relative load, soft capacity, handover events
Admission Control in WCDMA
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ABSTRACT
When operating a cellular radio system nearly at full capacity, admitting yet another user may jeopardize the stability of the system as well as the performance of the individual users. Therefore, proper admission control is crucial. The core idea in this work is to predict the relative load of the system, given that a user is admitted. Then, the user will be admitted if the predicted load in the specific cell, and in its neighbors, is below some threshold. This provides an interesting alternative to algorithms based on hard capacity, which might be utilizing the resources inefficiently in order to be robust. The proposed uplink admission control algorithm is focused on WCDMA and utilizes measurements readily available in that system. Simulations indicate performance improvements. Furthermore, multi-services are naturally handled, and availability of high data-rate services are automatically limited with respect to coverage, compared to services of lower data-rate.

I INTRODUCTION
Admission and congestion control are important radio resource management mechanisms used to maintain acceptable service quality of existing connections. Admitting too many users results in a situation where the mutual interference between the connections degrade the quality of service. If such a situation arises, appropriate congestion control discontinues the service or reduces the data rate of some connections, to save the others. In general, it is more infringing to interrupt a service than to deny it in the first place.

The core idea of admission control is to admit users only if there are available resources to support their service requirements. A natural admission control strategy in a single service system (e.g., voice) is to limit the absolute number of users (or the number of links when users are in soft handover) in each cell, and only admit a new user if below this limit. This is referred to as hard capacity. The strategy can also be used in multi-service systems, by considering higher data-rate users as multiple low data-rate users capacity-wise. An alternative is to base the admission control on measurements or estimates (typically the total received power or interference) relating to the actual load of the system, which is referred to as soft capacity [7].

Many uplink admission control algorithms are based on total received power or the relation of the same to the thermal noise at the base stations. Such strategies include [2, 7–9, 11, 12]. An alternative is to use SIR measurements at the base station, which is further explored in [10, 14]. Admission control for multimedia traffic is the main issue in [1, 3, 13, 16]. The load of the cellular radio system is truly a spatial quantity, and therefore hard to describe by a single number. However, some efforts are made in [5, 6].

One problem with algorithms based on the total interference is that accurate measurements are typically not available. In this contribution, we discuss uplink admission control based on a measure of the relative (or fractional) load [5, 7, 8] of the system and estimates thereof using only available measurements. A similar strategy, but for uplink packet access control, is considered in [17]. The idea is further explored here for real-time, connection-oriented services, and extended to also include soft handover.

The results are also reported in [4]. Section II presents relevant models and notation. These are utilized in Section III, where we are more elaborate about capacity and relative load of cellular radio systems. These quantities are typically neither fully observable, nor directly controllable in practical implementations. Some tractable admission control algorithms based on relative load estimates are also discussed. The algorithms are evaluated and compared to hard capacity algorithms in simulations in Section IV, and Section V provides some conclusive remarks.

II SYSTEM MODEL
Most quantities in this paper can be expressed using either logarithmic (e.g. dB or dBm) or linear scale. To avoid confusion we will employ the convention of indicating linearly scaled values with a bar. Thus, \( \bar{g}_{ij} \) is a value in linear scale and \( g_{ij} \) the corresponding value in logarithmic scale.

Consider an uplink situation in a cellular radio sys-
tem, with \( B \) base stations. (In this work, we will denote different sectors at the same cell site as different base stations.) Assume that the \( M \) active mobile stations are transmitting using the powers \( p_i(t) \), \( i = 1, \ldots, M \). The signal power from mobile station \( i \) and base station \( j \) (\( j = 1, \ldots, B \)) is attenuated by the power gain \( g_{ij}(t) < 1 \). The uplink propagation situation in a cellular network can thus be described by the power gains, which together form the uplink gain matrix

\[
\mathbf{G}(t) = [g_{ij}(t)] = \begin{pmatrix} g_{11}(t) & \cdots & g_{1B}(t) \\ \vdots & \ddots & \vdots \\ g_{M1}(t) & \cdots & g_{MB}(t) \end{pmatrix} \tag{1}
\]

This matrix is most likely not square, since there are more mobile stations than base stations in a cellular radio system. If the mobile station \( i \) is connected to base station \( j \), this base station will experience a carrier power \( C_i(t) = p_i(t)g_{ij}(t) \). All the received signals and thermal noise (with power \( \nu_j(t) \)) at the base station combine to the total interference power (total received power):

\[
I_{j\text{tot}}(t) = \nu_j(t) + \sum_{i=1}^{M} g_{ij}(t)p_i(t) \tag{2}
\]

The perceived quality is related to the carrier-to-interference ratio (CIR) defined by

\[
\gamma_i(t) = \frac{C_i(t)}{I_{i\text{tot}}(t) - C_i(t)}. \tag{3}
\]

For presentation ease, we will in some sections instead use the carrier-to-total-interference ratio (CTIR), \( \tilde{\beta}_i(t) = C_i(t)/I_{i\text{tot}}(t) \). In a simplistic situation the quality of a specific service, for example in terms of data rate or bit error rate, can be related to a required CIR, denoted target CIR, \( \gamma_i^t(t) \). This target is possibly reconsidered regularly by outer control loops [5]. The outer loop update rate is typically orders of magnitude faster than the admission control, and the changes are relatively small. Therefore, the target SIRs will be considered constant.

An admitted mobile station is allocated

- a connection to a base station (typically, the one with most favorable propagation conditions, i.e., highest \( g_{ij} \)).
- a waveform (in DS-CDMA, a code).
- a transmission power \( p_i(t) \). The aim is to update the power so that CIR is equal to target CIR, \( \gamma_i(t) = \gamma_i^t \).

These allocations are regularly reconsidered by radio resource management algorithms. Power control is much faster than admission control. When studying admission control, it is therefore natural to assume perfect power control, i.e., \( \gamma_i(t) = \gamma_i^t \).

DS-CDMA allows a mobile station to be connected to a multitude of base stations at different cell sites (soft handover) or to several base stations at the same cell site (softer handover). Denote the set of connected base stations of mobile station \( i \) by \( K_i \). When in softer handover, the cell site can combine the received signals in an optimal manner. Using this maximum ratio combining, the CTIR is given by

\[
\tilde{\beta}_i(t) = \sum_{k \in K_i} \frac{\bar{g}_{ik}(t)\bar{p}_k(t)}{I_{k\text{tot}}(t)} \tag{3}
\]

Conversely, when connected to different cell sites as in soft handover, selection combining is used and the signal with the best CTIR is chosen.

### III RELATIVE LOAD AND UPLINK ADMISSION CONTROL

In this section, we will derive a practical estimate of the relative load from literature, to form a tractable admission control algorithm. For notational ease, the time index \( t \) will be suppressed throughout the section.

#### Relative Load

The maximal load of a base station in a sparsely planned second generation TDMA/FDMA system is solely determined by the number of frequency channels (times the number of time slots) at that base station. In densely planned systems such as a WCDMA system or a GSM system with all available frequency channels at every base station, the maximal load is determined by the propagation situation between mobile and base stations. Therefore, the capacity of the system is to its nature soft and varying but slowly with time.

As motivated in [7, 8, 15, 17], the total interference at base station \( j \) can be expressed as

\[
I_{j\text{tot}} = \frac{\bar{\nu}_j}{1 - L_j}, \tag{4}
\]

where \( \bar{\nu}_j \) is the thermal noise power and \( L_j \) is denoted the relative or fractional load. An intuitive interpretation is that \( L_j = 0 \), which means that the interference is only thermal noise, corresponds to the situation when the cell is not loaded. Conversely, \( L_j = 1 \) is synonymous to infinite interference power and thus an upper load limit. The relation in (4) can be rewritten as

\[
L_j = \frac{1}{1 - \bar{\nu}_j} \Leftrightarrow \bar{L}_j = 1 - \frac{1}{I_{j\text{tot}}/\bar{\nu}_j}. \tag{5}
\]

The ratio \( I_{j\text{tot}}/\bar{\nu}_j \) is referred to as the noise raise and is thus a measure of the load of the system. For example, the objective in [7] is a noise raise of 4 dB, which corresponds to \( L_j \approx 0.6 \).

Now, we aim at a relative load estimate \( \hat{L}_j \), which approximately holds true for the relation in (4). It is based on available measurements and will be used for uplink admission control in the following subsection.
Assume that the CTIR expression for softer handover in (3) is approximately true also for soft handover. This yields

$$\hat{\beta}_i = \hat{\beta}_i \sum_{k \in K_i} \hat{g}_{ik} \iff \hat{\beta}_i = \frac{\hat{\beta}_i \sum_{k \in K_i} \hat{g}_{ik}}{1} \forall i$$

(6)

Combining Equations (7) and (6) results in

$$I_{j}^{\text{tot}} = \tilde{\nu}_j + \sum_{i=1}^{M} \tilde{g}_{ij} \hat{\nu}_i + \sum_{i=1}^{M} \frac{\tilde{g}_{ij} \hat{\beta}_i}{\sum_{k \in K_i} \hat{g}_{ik}}$$

(7)

Furthermore, we elaborate with the temporary approximation that the total interference powers at the different base stations are equal, $I_{j}^{\text{tot}} = I_{j}^{\text{tot}}$. Solve for $I_{j}^{\text{tot}}$, yields

$$I_{j}^{\text{tot}} \cdot L_{j}^{\text{tot}} = \frac{\hat{\nu}_j}{1 - \sum_{i=1}^{M} \frac{\tilde{g}_{ij} \hat{\nu}_i}{\sum_{k \in K_i} \hat{g}_{ik}}}$$

This expression is of the desired form in (4), and it is therefore natural to introduce the load estimate

$$L_{j} = \sum_{i=1}^{M} \frac{\hat{\nu}_i \hat{\beta}_i}{\sum_{k \in K_i} \hat{g}_{ik}}$$

(8)

An Uplink Admission Control Strategy

The relative load estimate in (8) can be used to determine whether there is room for yet another mobile station in the system. It is therefore of value for admission control. However, power gain measurements are needed. They can be made available in two different ways:

M1: The mobile stations are requested to periodically (but not necessarily synchronously) report pilot power measurements from the five strongest base stations at a rate of for example 0.5 Hz.

M2: For handover purposes, the mobile typically reports similar measurements in an event-driven fashion. It measures the pilot powers from the neighboring cells and reports up to the six strongest power gains at handover events. Such events are triggered by a number of situations, for example that the pilot power from one base station is significantly higher than before.

In both cases, the channel is assumed reciprocal, i.e., the uplink power gain is assumed approximately equal (at least with respect to path gain and the shadow fading) to the corresponding downlink power gain. Furthermore, these different strategies only provide data from a limited set of mobile–base power gains. The remainder, however, are considered small and set equal to zero.

When a mobile station requests admission in base station $j$ for a service corresponding to a target SIR $\gamma^i_t$, the resulting load can thus be predicted.

\begin{algorithm}

\textbf{Algorithm 1: Uplink Admission Control Using a Relative Load Estimate}

\textbf{Input:} List of neighboring cells $N_j$, Power gain measurements from the mobiles including the mobile requesting admission in cell $j$ (gains to distant base stations not included in the measurement report from the mobile are considered zero), CTIR targets, $\hat{\beta}_i$.

i) Predict the new load in cell $j$ and the set of neighboring cells $N_j$ to cell $j$ using $L_{j} = \sum_{i=1}^{M} \frac{\tilde{g}_{ij} \hat{\beta}_i}{\sum_{k \in K_i} \hat{g}_{ik}}$

ii) Admit the user only if $L_{j}$ and $L_{n}$, $n \in N_j$ all are below $\delta_{SC}$.

\end{algorithm}

\textbf{IV SIMULATIONS}

The different algorithms are compared in network simulations. Performance is illustrated both in single service and in multi-service scenarios.

\textbf{Single Service}

To compare admission control using hard and soft capacity respectively, we consider a WCDMA-type systems with the only service 192 kbps streaming data (chosen to create a considerable load while limiting the number of users to ease the computational burden). The simulated scenario describes a suburban situation with 21 base stations, intermediate velocities (50 km/h), shadow fading ($d_0=30$ m, $\sigma = 6$ DB), fast fading and RAKE receivers. To maintain a high load situation, there are always new users waiting for admission in every cell. The hard capacity algorithm admits the user only if the number of links (in a soft handover, the mobile has a $1/N$ link to each of the $N$ connected base stations) is less than $\delta_{HC}$.

The objectives from [7] mentioned in the previous section (noise raise $\approx 4$ dB) roughly corresponds to soft capacity, $\delta_{SC} = 0.6$ (event-driven measurements, M2) and hard capacity, $\delta_{HC} = 3$. The two algorithms are compared in Figure 1. We note that they roughly load the system equally well, but that the soft capacity algorithm manage to fit in more users. By varying the design parameters $\delta_{SC}$ and $\delta_{HC}$, the relation between how many users that are accommodated and the resulting noise raise can be formed. As seen in Figure 2, the algorithms are not very different. It is somewhat surprising that the benefits of soft capacity are not evident. However, this is partly due to that soft capacity is only considered at admission, and the user mobility may alter the load of the system over time. Furthermore, congestion control, which would down-grade the data-rate of costly users, is not implemented. Moreover, we note that there does not seem to be motivated to enforce the system to report additional measurements (M1). The event-driven measurements (M2) provide similar performance. Users close to a base station will report very seldom, but on the other hand, they are relatively cheaply accommodated compared to users on the cell borders. The latter, more costly, users will on the other hand report
Figure 1: Soft capacity, $\delta_{SC} = 0.6$, $M2$ measurements (thick line) and hard capacity, $\delta_{HC} = 3$ (thin line). a) Max. relative load from (5) over 100 frames and all base stations. b) Mean number of users using the two algorithms. relatively frequently. Hence, the measurements are updated more frequently where needed. As indicated by Figure 2, yet another benefit with soft capacity is the possibility of freely choosing the design parameter $\delta_{SC}$. Furthermore, it can be interpreted as the target load. Nevertheless, the resulting relative load will fluctuate around the target value, and it is of primary interest to study the worst-case behavior. Figure 3 illustrates the relation between the design parameter $\delta_{SC}$ and the 90-percentile of the noise raise for the two measurement situations. We also note a good correspondence to the theoretical relation in (5).

**Multi-services**

Since the service requirements of the users are described by the corresponding target CTIRs, $\beta_i$, multi-services are naturally considered. We will use two services: the high data rate user from the previous section, now moving at 3 km/h, and 12.2 kbps voice users moving at 50 km/h on average. Since the high data-rate users are more costly for the system, we assume that they will be admitted with limited coverage. This is truly the case as seen in Figure 4, which shows the histogram of the power gains for users admitted after an initial burn-in phase where the system is filled up. Figure 5 provide more information from two-service simulations (in this case with $\delta_{SC} = 0.5$). The algorithm manages to keep the load at a steady level (Figure 5a). It is also interesting to note (Figure 5b,c) that the voice users eagerly fill up the system when a high data-rate user disconnects. The total number of voice and data users are found in Figure 5d. One way of increasing the fraction of data users could be to use different thresholds for data and for voice

![Figure 2: The relation between accommodated users and resulting noise raise using the three algorithms: soft capacity, $M1$ (dashed line), soft capacity, $M2$ (thick line) and hard capacity (thin line).](image)

![Figure 3: Relations between the design parameter $\delta_{SC}$ and the 90-percentile of the noise raise for $M1$ (dashed line) and $M2$ (thick line), together with the theoretical relation in (5) (thin line).](image)

![Figure 4: Histograms of power gains for the services: 12.2 kbps (thin line) and 192 kbps (thick line).](image)

![Figure 5: Power Gain, $g_{ij}$](image)

**V CONCLUSIONS**

The proposed uplink admission control algorithm utilizes measurement readily available in the system. It is therefore an interesting alternative to algorithms based on interference measurements, which are known to be crude. The algorithm is tested both with enforced periodical measurements from the mobile stations, and with event-driven handover measurements readily available, and the performance is roughly the same. It can therefore be employed without signif-
Figure 5: Simulation results using soft capacity, \( M_2 \) and \( \delta_{SC} = 0.5 \): a) Max relative load from (5) over 100 frames and all base stations. b) Relative change of voice users over 10 frames. c) Same as b), but for data users. d) Total number of voice and data users over time.

significantly increasing the reporting load of the system. Multi-services are naturally handled, and a direct consequence is limited coverage for higher data-rate services compared to lower data-rate. The admitted traffic mix can, however, be altered by admitting higher data-rate users more easily.

REFERENCES


