Radio Resource Metric Estimation (RRME) Mechanism for Multimedia Service Applications based on a CDMA Communication System

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ABSTRACT

In this paper, we propose a predictive resource metric region (RMR) based radio resource metric estimation (RRME) mechanism, which utilizes a resource metric mapping function (RMMF), both of which permit efficient inter-working between the physical layer and higher layers for envisaging multimedia service applications over a CDMA communication system platform. The RMR can provide the acceptable resource region where QoS and acceptable link quality can be guaranteed with an achievable resource margin to be utilized in terms of capacity margin, the degree of confidence (DCL) of user, second-order statistics of Eb/Io. With predicted capacity margin and variance, DCL can deliver decision parameters with which an adaptive QoS based admission control can perform well taking capacity and resource availability into account in a dynamic and predictive manner. Combined with advanced techniques such as adaptive modulation or rate control and power control, the proposed mechanism can adjust the conventional stringent link quality information efficiently, and deliver accurate information of the resource availability. Thus, these can guarantee the maximization of resource utilization of multimedia service applications.

***Keywords**: RRME, multimedia, CDMA, cross-layer, QoS*

1. INTRODUCTION

It is important with future differentiated services to be delivered via mobile networks for adaptability in terms of resource estimation, utilization and allocation. In next generation wireless communication systems the optimization of resource use in the radio resource management (RRM) will be a key driver. Current RRM functionality in 3G and beyond systems acts from the network layer down to the data link and physical layer, thus the wireless physical resources are utilized directly without intermediate layers. Therefore, research work incorporating an RRM that takes account of the conditions of the physical layer resources suggests the need to focus on its potential impact in the intermediate layer, i.e. radio resource metric estimation (RRME), which can be aware of the cross layer capabilities and states. Based on the knowledge of the desired loads and channel and radio resources, the RRM in cooperation with RRME can manage both up and down the protocol stack. Thus, it can decide and control the parameters and functions required to optimize the desired features such as QoS, throughput, power utilization and overall system capacity.

Radio resource metric estimation is a crucial part of the radio resource allocation (RRA) algorithm that performs call admission control (CAC), resource scheduling and power/rate scheduling tasks, which provides the following control tasks: 1) the radio channel characteristics and session quality requirements are used for optimal power and rate allocation, 2) the current channel load, characteristics and quality requirements are used for controlling the resource scheduler. With built-in capacity models, the RME assists the CAC in accepting or rejecting new sessions. The question of how to combine the interference measurements with the current load situation and QoS requirements of the existing traffic classes to control CAC, or channel allocation is a very interesting issue [1]. The generic RRME model and its operation with other functional blocks in the RRA operation at the BS are depicted in Fig. 1. Thus, the most appropriate resource metrics permit

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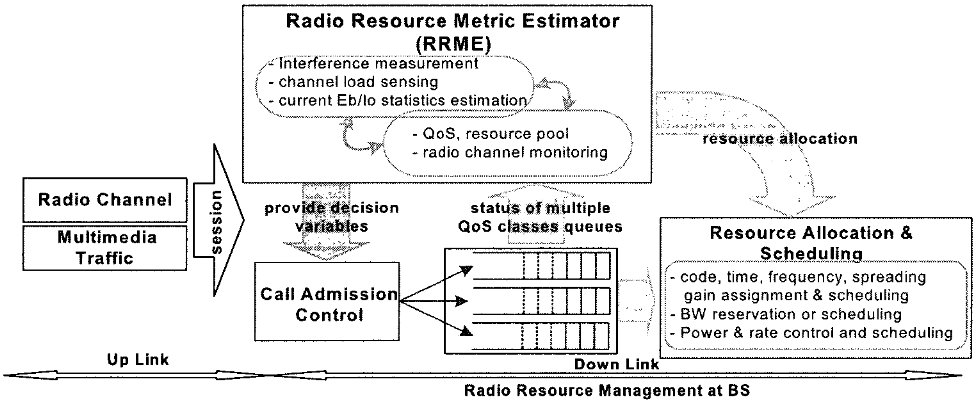

Fig. 1. Generic radio resource metric estimator in RRA algorithm at the BS

efficient inter-working between the physical layer and higher layers in the protocol stack and thus, it is essential to optimize the overall system performance. From the physical layer point of view, the most accurate method to access the actual measurements of the link quality estimation should be taken into account rather than just considering the resource management point of view. The role of RRME is to efficiently deliver the measured link quality information to the CAC and other parts of RRA algorithm, which shares a common aim with the interface between the link level simulation and system level simulation. Hence, as one of candidate solutions of how the RRME can provide fast and reliable resource information to a higher layer in an efficient manner, we had proposed a radio resource metric mapping function (RMMF) associated with the RRA in the previous study[2]. This function deals with the issue of how to combine the interference measurements relevant to current load and traffic condition to control call admission control.

In this paper, as a solution for efficient cross-layer inter-working, we propose a predictive resource metric region (RMR based RRME mechanism that permits efficient inter-working between the physical layer and higher layers, which is applicable to wireless CDMA communication systems for multimedia service applications. The proposed RRME method can provide achievable resource information to be utilized in terms of capacity margin, its degree of confidence level (DCL) and second-order statistics of Eb/Io. With such parameters, it is demonstrated that the predictive resource metric region based RME can perform the dynamic and predictive resource allocation decision. In Section II the capacity plane by optimal call admission control is shown and the proposed RRME method is described in Section III. The multimedia traffic model and simulation results are shown in Section IV and the conclusions are driven in Section V.

2. CAC CRITERION AND CAPACITY PLANE

2.1 Power Controlled Call Admission Control

The current capacity status $\widetilde{K}$ can be estimated by judging the call admission control decision criterion for power controlled multi-rate system as in the following [3][4]:

$$f(\varepsilon,G,h)=\sum_{j=1}^{K}\frac{\varepsilon_j}{\varepsilon_j+G_j}+\frac{\eta_0 W}{\min\limits_{1\le i\le K}\left[P_{\max,i}h_i\frac{\varepsilon_i+G_i}{\varepsilon_i}\right]}<1 \qquad (1)$$

where W is the system bandwidth, G_j is the processing gain, the channel coefficient h_j, and η_0 is the noise spectral density. K is the total number of mobile users admitted in the system, which is the total sum of each user supporting corresponding data rate classes $K=\sum_{i=1}^{N}K_i$ where N is the total data rate service classes. In our study, we consider three kinds of service classes, voice, video, and data, of which number of users are denoted as K_v, K_{vid}, and K_d, respectively. ε_j is the required *Eb/Io* for *i*-th user, which is defined by

$$\varepsilon_i=\frac{G_i h_i P_i}{\sum_{j\ne i}^{K}h_j P_j+\eta_0 W} \qquad (2)$$

The maximum number of supportable user K is determined by the predefined outage probability, which is set to as 0.01 in our study.

2.2 Impact of Systematic Error on Capacity Plane

As shown in Fig. 2, the theoretical maximum available pair of numbers of users (K_v,K_d) with different data rates and QoS requirements for a given number of video users is significantly dependent on the variance of *Eb/Io*, caused by the systematic error such as inaccurate power control, traffic variation, and fading. Fig. 3 shows the maximum aggregated data rate (ADR) defined by the total sum of the numbers of users multiplied by their corresponding data rate, i.e. ADR=($K_vR_v+K_{vid}R_{vid}+K_vR_v$). If the systematic error (here, this is the standard deviation of *Eb/Io*) is increased, with the admission control criterion as in Eq. (1) the maximum available number of users and the ADR are dramatically reduced as shown in Fig. 2. Thus, it is necessary to consider the variance of the received *Eb/Io* along with the possible maximum capacity margin according to its situation.

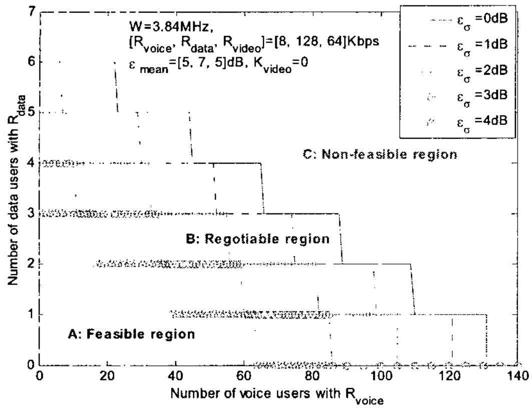

Fig. 2. Maximum capacity plane for a fixed number of video users with different systematic errors.

When the number of users satisfying the QoS requirement is determined based on the measured and estimated load, this can be categorized as; (A), feasible region; (B), negotiable region; (C), non-feasible region, depending on current load status and the amount of capacity margin. The capacity margin in region (B) shown in Fig. 2 is too stringent to admit or reject a call in a conventional system although it has still available resources. Thus, we propose the Kalman filter based RRME, which is dependent on the standard deviation of capacity and the DCL of capacity and user's status that can be driven from second-order statistics of *Eb/Io*. Note that the higher the variance of the *Eb/Io* the lower maximum capacity, capacity margin, and resource availability. For an estimation of the maximum available number of users and available resource margin, both the received *Eb/Io* and the variance of *Eb/Io* have to be taken into account.

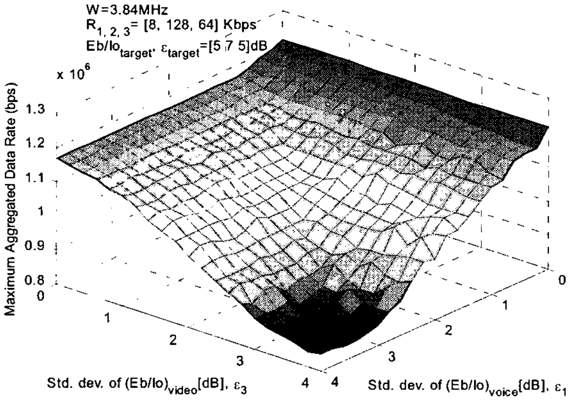

Fig. 3. Maximum ADR as a function of standard deviations of required *Eb/Io* target for different data rate services, ε_v^σ and ε_{vid}^σ.

3. RADIO RESOURCE METRIC ESTIMATION MECHANISM

In this section, the proposed resource metric region based predictive RRME method is described, which can provide the acceptable resource region where QoS and acceptable link quality can be guaranteed with an achievable resource margin to be utilized in terms of the RMMF.

3.1 Resource Metric Mapping Function (RMMF)

The RMMF enables efficient utilizing and monitoring in resource usage using the interface between link level and system level simulations which enables dynamic resource metric estimation, such that the current channel load conditions and resource pool condition can be achieved in a non-averaged manner. The procedure of the RMMF can be summarized as following three stages: 1) channel characterization on a burst-by-burst basis, 2) extracting burst information from link level, and 3) estimating link quality which can be raw BER, block error rate, or frame error rate. By using the RMMF, the link quality in terms of average raw BER observed by a user can be determined very accurately. In higher layers, this mapping function can be used as a resource look-up table having actual radio mobile channel and interference characteristics and as a monitor of resource availability or efficiency [2].

3.2 Predictive Resource Metric Region based RRME

In an aggregated traffic stream the estimation of available resource can be either optimistic or conservative due to the inaccurate link quality information and the coarse estimation of overflow traffic, and thus all the resource units cannot be exploited. If we know the resource availability, i.e. the required total average resource plus the excessive resource which cannot be utilized because of stringent call admission criterion, then this information allows the acceptable resource metric region to be established on a call, a packet, or a time slot basis, thus enabling resource allocation algorithm to maximize the resource utilization.

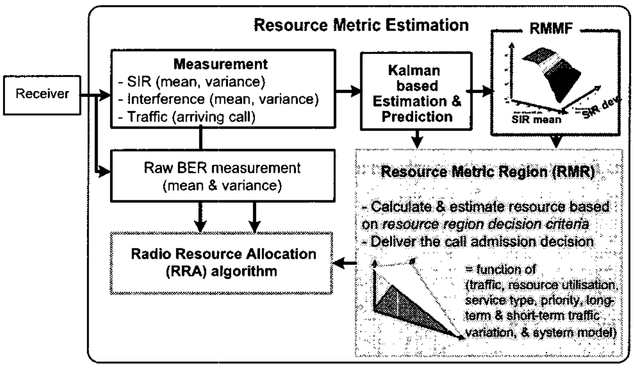

Fig. 4. Block diagram of the predictive resource metric region based radio resource metric estimation.

Our approach to this concept is depicted in Fig. 4, where the measurement of SIR and traffic followed by a Kalman filter based prediction is performed. This provides measured or predicted resource parameters for the resource scheduler to search their current position on the surface of the RMMF and to deliver the actual status of the resource usage. All of these are integrated by establishing resource RMR (resource metric region) in which the calculation and estimation of resource availability are performed based on the resource region decision criteria and help the call admission decision on a call, a packet, or a time slot basis.

As mentioned before, the capacity margin in the negotiable region is too stringent to admit or reject a call in a conventional system although it has still available resources. Thus, we propose Kalman filter based RRME with the DCL of capacity and user's status that can deliver the available capacity or resource margin, considering the systematic error. The procedure of the proposed predictive RME method is summarized as followings:

(1) BS measures the mean and standard deviation of received *Eb/Io*:
(2) BS estimates the current load condition, interference level, and satisfied users:
(3) Then, BS decides the current capacity region:
(4) With Kalman predictor, BS predicts capacity margin. The predicted capacity margin or variation (ΔK) can be rewritten as $\Delta f(\hat{\boldsymbol{\varepsilon}},\hat{\boldsymbol{\varepsilon}}_{\sigma},\hat{\mathbf{h}},\hat{\mathbf{G}},c)$ from Eq. (1) with some modifications, which takes the current and predicted standard deviation of *Eb/Io* into account. Thus, the final predicted available number of user $\hat{K}$ is given by sum of the estimated K by Kalman filtering and its variance ΔK , i.e. $\hat{K} = \tilde{K} + \Delta\tilde{K}$:
(5) DCL calculates the weighting factor considering the current and predicted capacity margin and statuses of users belonging to one of all possible regions and delivers these to RRA algorithm to accept or reject a new coming call.

- ***Degree of confidence level:*** It is the main feature of proposed RRME method, which is defined as the capacity status by comparing the distance from the optimal capacity limit and the pessimistic capacity limit to estimated current user status with the amount of the predicted variation of available number of user, either increased or decreased by the Kalman predictor (ΔK). This means that it is mainly dependent on the current and predicted capacity margin and statuses of users belonging to one of all possible states, e.g. current state (region (A), (B), or (C)) → predicted state ((A), (B), or (C)) as shown in Fig. 6. Depending on the status of current user's capacity region, corresponding DCL can be calculated in a quite different manner as shown in Fig. 5. This DCL example applicable to wireless CDMA systems is quite dependent on system assumptions such as maximum available negotiable region, maximum capacity limit corresponding to system parameters, and the fidelity of estimator and predictor, as well as service traffic characteristics. From the QoS point of view, the DCL can provide a decision parameter with which adaptive QoS based admission control can perform taking capacity and resource availability into account in a predictive manner.

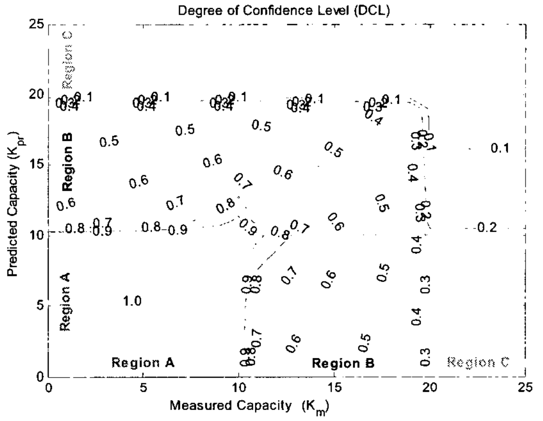

Fig. 5. Degree of confidence level.

- ***Call admission control for multimedia service traffic:*** In order to fully utilize available resource (or residual capacity), the monitoring real time traffic (RTT) load and controlling non-real time traffic (NRTT) packet data traffic is crucial in multimedia traffic call admission control. Since RTT calls are always given the highest priority and they are allowed to transmit without delay, in our study, NRTT calls are allowed to transmit according to the available residual capacity (available capacity, herein, the residual ADR) obtained by subtracting the real time traffic contribution from the total system capacity (maximum ADR). Thus, the resource availability for data service is determined by estimating and predicting the real time load contribution for the next time state. We applied Kalman filter interference prediction as in [5] with some modifications to ADR prediction.

4. SIMULATION MODEL AND RESULTS

A single micro cell configuration in which a set of power controlled mobile terminals are transmitting packets to a BS, in a CDMA system, is considered. With uplink channel, RTT (voice calls and video-phone calls) and NRTT mixed traffic are considered. We generate the video-phone traffic model as in [6] for H.263 video sequence of which distribution is assumed to be Gamma distribution. The call arriving of each service is modeled as Poisson random variables with corresponding exponential distributed holding time. For data traffic, packet switched Web browsing traffic is considered. The system level multimedia traffic parameters are shown at Table 1.

Table 1. Multimedia traffic simulation parameters

Parameter	Value
System bandwidth, W [MHz]	3.84
Noise spectral density, η_0 [dBm/Hz]	-174
Max. MS power limit (voice, video, and data) [dBm]	5, 80, 40
Standard deviation of shadowing [dB]	10
Mean of required Eb/Io for voice, data, and video; $\varepsilon_v^{req}, \varepsilon_d^{req}, \varepsilon_{vid}^{req}$ [dB]	5, 7, 5
Data rate for voice, packet data, and video; R_v, R_d, R_{vid} [Kbps]	8,128, 64
Maximum available number of users for voice, video, and data within a frame; $K_v^{\lim}, K_d^{\lim}, K_{vid}^{\lim}$	50, 10, 10
Poisson call arriving rate; $\lambda_v, \lambda_d, \lambda_{vid}$ [call/frame]	3, 2, 1
Mean call holding time; ht_v , ht_d , ht_{vid} [frame]	5,10,5
Outage probability constraint, Pr_{out}	0.01

Results with simulated arriving multimedia traffic are shown in Fig. 6 and Fig. 7 where the systematic error including power control error, standard deviation of received *Eb/Io* ($\varepsilon_v^{\sigma} = \varepsilon_d^{\sigma} = \varepsilon_{vid}^{\sigma}$) are assumed 0 dB and 2 dB for three service types, respectively. Once these requests are received and measured at BS, traffic information goes to a resource metric estimation with RMR in Fig. 4 through Kalman predictor, DCL decision, and resource admission control algorithm. As shown in Fig. 6 (b) and Fig. 7 (b), admission controlled multimedia traffic is filtered out by Eq. (1) criterion. Due to the systematic error most of data traffic are blocked or forced to be blocked whilst RTT is served at their request data rate transmission, since it only causes a fluctuation in the maximum available capacity. With application of DCL concept and Kalman measuring window size (N) of 10 frames and 3dB measurement error, the predicted RTT load, the predicted residual ADR (predADR), and the DCL weighted predicted residual ADR (DCL-predADR) are plotted in Fig. 8 and Fig. 9 according to systematic error. Here, the DCL is built up by the ADR region instead of capacity, since ADR itself contains information of number of users for each service class. In Fig. 8 (b) and Fig. 9 (b), the predADR is obtained by subtracting the predicted RTT ADR from the theoretical maximum ADR that gives available data rate for NRTT. The DCL-predADR is given by weighting DCL factors to the predADR value on a specific prediction window size. Compared to the predADR, DCL-predADR can deliver the reliable status of resource availability.

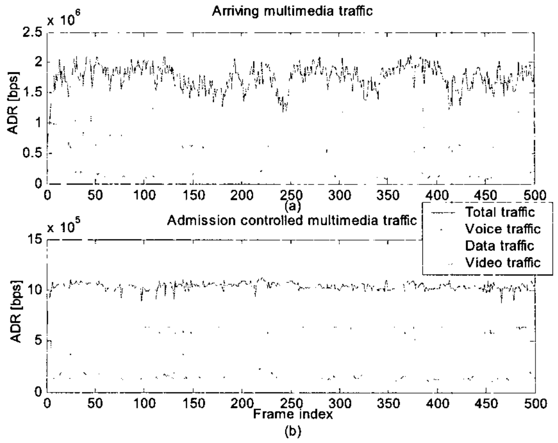

Fig. 6. Simulated multimedia traffic ($[\lambda_v, \lambda_d, \lambda_{vid}]$ =[3, 2, 1] call/frame) with no systematic error.

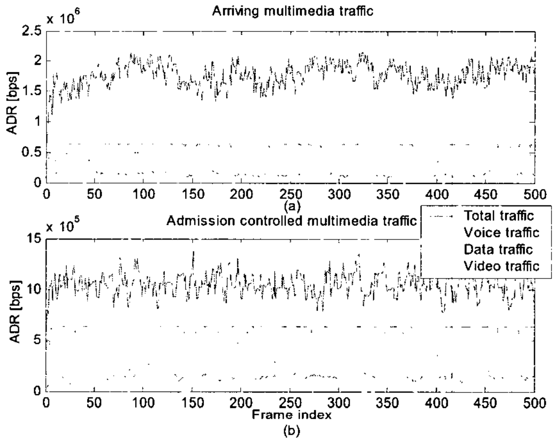

Fig. 7. Simulated multimedia traffic ($[\lambda_v, \lambda_d, \lambda_{vid}]$ =[3, 2, 1] call/frame) with 2 dB standard deviation of required *Eb/Io* target.

In Fig. 8 (b), it is observed that DCL-predADR indicates a slightly cautious prediction compared to an optimistic predADR result since DCL values are fluctuating due to the large variation of predicted RTT, showing around 0.5. That is, the system status mainly belongs to the negotiable region (B) or is moving to that region; which means the current available resource cannot be fully utilized because of high possibility of the system not being able to accept every requesting calls. So, the DCL-predADR in Fig. 8 (b) slightly undervalues residual ADR reflecting future resource availability and capacity status. Compared to this result, DCL-predADR for 2dB standard deviation of required *Eb/Io* shown in Fig. 9 (b) indicates a pessimistic prediction result since the predADR is already quite low due to the variation of required *Eb/Io* target varying with a 2 dB deviation. With this systematic error, the maximum theoretical capacity limit shrinks down to satisfy the outage probability constraint and thus, the available residual capacity also gets decreased.

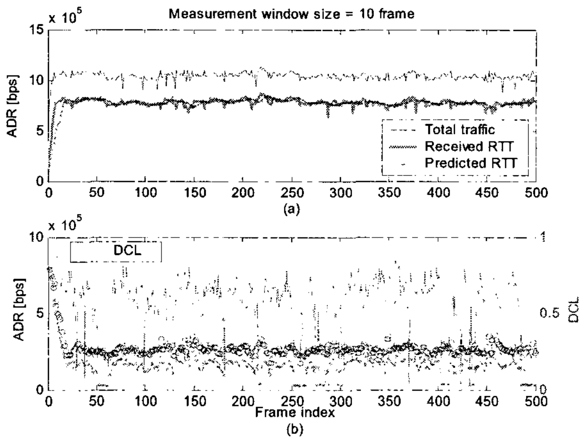

Fig. 8. Predicted RTT, predicted residual ADR (predADR) and DCL weighted predicted residual ADR (DCL-predADR) for no systematic error with N=10 frames.

However, when the predicted residual ADR and the status of system capacity with DCL are considered at the same time, the DCL-predADR gives a less pessimistic prediction as that in Fig. 8 (b) but a more reliable adjusted prediction not to fall into "the deflation". The maximum value of DCL shown in Fig. 5 might be set to larger than 1 according to the variation of capacity (the standard deviation of required *Eb/Io* target). Thus, DCL-predADR predicts slightly optimistic value compared to predADR since predADR is based on theoretical maximum capacity limit that cannot always be right value particularly in a systematic error situation.

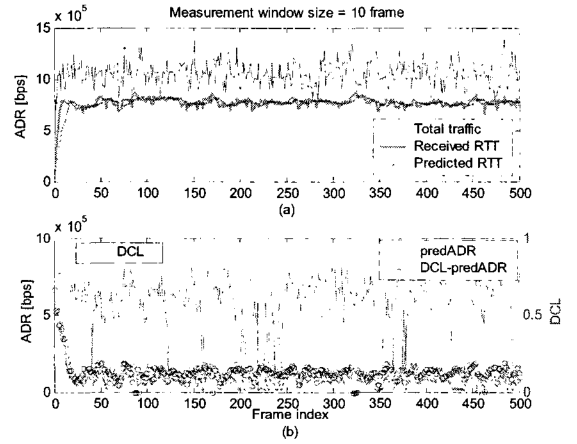

Fig. 9. Predicted RTT, predicted residual ADR (predADR) and DCL weighted predicted residual ADR (DCL-predADR) for 2 dB standard deviation of required *Eb/Io* target with N= 10 frames.

Thus, it is concluded that DCL-predADR has the function of increasing the fidelity of prediction and adjusting the sensitiveness of call admission control algorithm by preventing the CAC algorithm from falling into too pessimistic or optimistic information of the next time state. The DCL weighted predicted residual ADR can be easily converted into resource unit such as time slot, code, and rate. Even though Fig. 8 (b) and Fig. 9 (b) do not use these kinds of resource units directly, these indicate the availability of residual ADR (or capacity) that should be delivered to expecting NRTT data packet users and be used to control their call request or on-going data packets. Moreover, the DCL-predADR can provide the exact achievable resource margin to packet data users and thus, with this information, packet data users can adjust transmitting data rate adaptively.

5. CONCLUSIONS

In this paper, the resource metric region based predicted RRME method utilizing a RMMF has been investigated. This can provide the acceptable resource region where QoS and acceptable link quality can be guaranteed with an achievable resource margin in terms of capacity margin, the degree of confidence level (DCL) of user, and second-order statistics of *Eb/Io*. With the predicted capacity margin and variance, DCL can deliver decision parameters with which adaptive QoS based admission control can perform well, taking capacity and resource availability into account in a dynamic and predictive manner. Thus, DCL weighted predicted capacity can be converted into the resource unit, since all the possible resource unit such as code unit, time slot, and frequency unit (if multi-carrier considered) can be directly related with data rate and its corresponding processing gain. Furthermore, if combined with adaptive modulation and power control, or rate control and power control, the proposed method becomes a much more crucial decision parameter provider which can adjust the conventional stringent link quality information, or the uncertain information of the resource availability.

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