Random Access Channel (RACH) Parameters Optimization in WCDMA Systems

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***Abstract*—The random access procedure, defined by 3rd Generation Partnership Project (3GPP), is based on a slotted Aloha approach with fast acquisition indication, that is carried out in uplink by the Random Access Channel (RACH) and Acquisition Indicator Channel (AICH) in the downlink. In this paper, the RACH performance in a single omni cell under shadowing and fast-fading conditions is analyzed. An optimization procedure is performed to obtain, according to random access delay and random access success ratio, optimal values for RACH radio parameters such as the power offset between consecutive preambles (Δ_{pp}) and the preamble target Signal to Interference Ratio (SIR_t). Furthermore, curves of preamble Signal to Interference Ratio (SIR), measured at Base Station point, are presented.**

Keywords-component; Random access channel, WCDMA systems

I. INTRODUCTION

In Wideband CDMA (WCDMA) mobile communication networks, the system capacity is commonly limited by interferences. Since the power is the principal shared radio resource, one of the fundamental tasks within WCDMA systems is to control the uplink power accurately.

The Random Access Channel (RACH) is a common uplink channel that can be used for the initial contact of mobile users to the base station and for short data packets transportation. The random access procedure is based on slotted Aloha approach with fast acquisition indication carried by the AICH [1]. In the RACH transmission an open loop power control is used, that is less accurate than the closed loop control.

Preceding works on the performance of RACH channel in WCDMA were centered on the RACH throughput from Node B perspective. In [4], authors simulate a single demodulator RACH and investigate the impact of message length and number of signatures used. This study shows that the capacity is significantly higher than in the slotted Aloha case. Reference [5] describes the throughput degradation at high loads due to the tight power restrictions necessary in a CDMA system. Furthermore, throughput performance of two open loop channels, the RACH and Common Packet Channel (CPCH), is studied in [6] where is demonstrated that throughput numbers for both schemes are comparable. The random access delay is an important performance indicator as [7] analyzes, together with throughput.

The link level performance of the power ramping of RACH and AICH indication is described in [8]. In addition, the Frame Error Rate (FER) performance vs. average Eb/N0 has been discussed for vehicular and indoor environments in [9], where it is shown that indoor channels present higher FER.

In this paper, the RACH performance in a single omni cell under shadowing and fast-fading conditions is analyzed. An optimization procedure is carried out to obtain, according to random access delay and random access success ratio, optimal values for RACH radio parameters such as the power offset between consecutive preambles (Δpp) and the preamble target Signal to Interference Ratio (SIRt). Furthermore, curves of preamble Signal to Interference Ratio (SIR), measured at Base Station point are presented.

This paper is organized as follows. A brief description of the random access algorithm defined in [1] and [2] is given in section II of the paper. The proposed simulation model is presented in section III, where input traffic load and RF channel modeling are explained. Section IV gives the result and discussion of simulations. Finally, conclusions are addressed in section V.

II. RACH PROCEDURE

The random access procedure is performed by two lower layers: the Physical Layer (PHY), that manages preambles and ACKs, and the Medium Access Control Layer (MAC), that controls PHY retransmissions. The procedure is based on the transmission of one or more preambles and a message to the base station. The preamble consists of the 256 repetition of a 16 symbol signature, i.e. 4096 chips, therefore, there is no user information in the preamble. The message part consists of Layer 2 data information and Layer 1 control information.

At the start of the RACH procedure, the UE randomly selects a signature from the set of available signatures within its Acess Service Class (ASC), transmits a preamble and then, waits for an acquisition indicator on the AICH. In case of the base station detects the preamble and there are enough resources (demodulators) to serve the incoming message, it sends an ACK on AICH to that given signature. Three access slots after the UE receives the AICH confirmation, it will transmit the message part with data and control information. If No ACK is received at UE side, due to the signature is not detected at base station, the PHY procedure persists: the UE ramps up its power and transmits a new preamble. In the third case, if there are not free demodulators to serve the new message, the base station rejects the access with an NACK on AICH and the UE performs a random backoff procedure to start a new PHY access.

The backoff procedure is controlled by MAC Layer and it could be started for three reasons: the UE receives a NACK to a preamble, the maximum number of preambles in a PHY process is reached, or the power exceeds the maximum allowed power by 6 dB. The MAC Layer ensures that no more than M_{max} PHY procedures will be repeated. In Fig. 1, the flow diagram of the RACH procedure is shown.

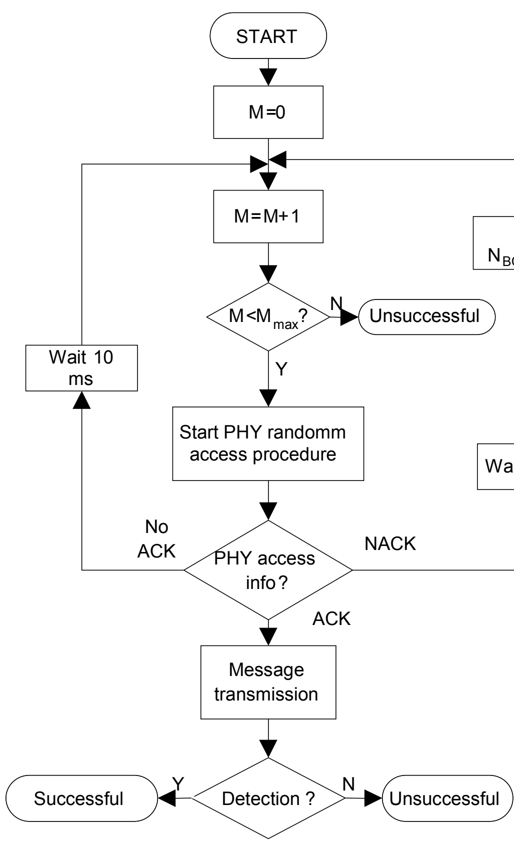

Figure 1. RACH flow diagram.

Time in RACH channel is divided in 20 ms frames (two 10 ms radioframes) that contain 15 access slots of 5120 chips each. The access slots are organized in 12 sub-channels. Therefore, the available resources for a given ASC are a set of sub-channels (among the 12 total sub-channels) and a set of signatures (among the 16 total signatures). The first preamble of each PHY procedure is transmitted in a randomly selected access slot among the available ones in the next access slot set; but, if more than one preamble is needed, the UE transmits in the next available access slot for its ASC. On the other hand, the UE always randomly selects a signature from the set of available ones.

III. Simulation Model

In the RACH channel, the power control is handled by an open loop scheme that is less accurate than the closed loop power control of dedicated channels. The transmission power of the first preamble of each PHY procedure is calculated by using an estimation of path loss and uplink interferences (broadcasted by the base station). We assume that a preamble or message is correctly detected if its SIR is above a threshold level, measured at the base station. Instead of transmitting a preamble with power enough to assure it will be detected, the UE tries to reach a fixed level of target SIR (SIR_t) that is below the threshold. Therefore, the first attempt will not succeed in many cases and the power will be increased stepwise for each burst.

As well as target SIR is an essential value, the Layer 1 of the UE must know the value of some radio parameters at the beginning of the access procedure. Table 1 shows the RACH parameters for the proposed model.

TABLE I. RACH Parameters

Parameter	Value
Persistence of MAC procedure, P_i	1
Maximum number of preambles per ramp	16
Maximum numbers of PHY backoffs, M_{max}	5
Maximum UE transmission power, P_{max}	23 dBm
AICH Timing	0
Number of backoff time intervals, N_{Bomin}-N_{BOmax}	0 – 50
Preamble to preamble power offset, Δ_{PP}	variable
Preamble to message power offset, Δ_{PM}	-2 dB
Target SIR for preambles, SIR_t	variable

Before transmitting the first preamble of the ramping procedure, the UE estimates its Preamble Commanded Power P_{TxUE} which compensates the path loss L_{Path} and uplink interferences I_{UL}. A Walfisch-Ikegami model is suggested, for the path loss simulation, because of it is the most suitable model for UMTS frequencies. Therefore, the path loss equation is shown in (1) and it is represented in Fig. 2, for a 750 m radius cell.

$$L_{Path}\left(dB\right) = \beta + 10\gamma \log\left(d\left(Km\right)\right), \quad (1)$$

where β=149.2441 and γ=3.8 for a metropolitan urban scenario and a frequency of 1950 MHz.

In a real situation, the UE calculates the path loss based on the received pilot power and the transmitted pilot power by base station, which value is broadcasted in a common channel. Consequently, the estimated path loss will differ from the theoretical one due to the pilot signal fading. That downlink fading is modeled by a gaussian function with 8 dB of standard deviation.

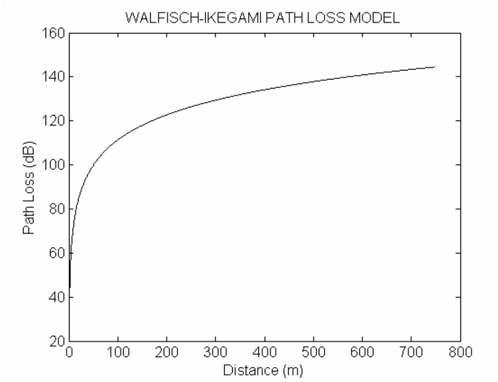

Figure 2. Walfisch-Ikegami propagation model.

Therefore, the preamble commanded power for the first preamble of a ramping cycle is given by (2)

$$P_{TxUE}\left(dBm\right) = SIR_t + L_{Path}(dB) + I_{UL}\left(dBm\right) - G_0\left(dB\right) \quad (2)$$

where G_0 is the resultant gain of antenna and connectors in uplink and I_{UL} is the average uplink interference over the last radio frame (10 ms).

The uplink interference is the addition, in mW, of the other RACH users interference and a floor level $I_{floorUL}$ that involves the thermal noise and the interference of channels in closed loop power control. The value of $I_{floorUL}$ is modeled by a Gaussian variable with –95 dBm mean and 2.5 dB of standard deviation

The open loop power control procedure is not accurate because the path loss differs between uplink and downlink frequency bands, and the uplink interference at the current slot may change from the average level in last radio frame.

Once a preamble is transmitted by the UE, signal suffers attenuation and fading in the air interface. to the base station. The mean of received power at the base station is calculated as

$$\overline{P_{RxBS}(dBm)} = P_{TxUE}(dBm) + G_0(dBm) - L_{Path}(dB) \quad (3)$$

where P_{TxUE} is the UE transmitted power, G_0 is the resultant gain of antenna and connectors in uplink and L_{Path} is the attenuation calculated by (1).

Superposing to $\overline{P_{RxBS}}$, we generate a Rayleigh random variable which represents fast fading envelope, of both preambles and message. This Rayleigh variable is filtered using a Jakes filter depending on the velocity of the UE. For our study, the velocity of mobile users is set to 4 Km/h. The mean of Rayleigh variable is modeled as a lognormal random variable with zero mean and standard deviation σ(dB)=8dB. The de-correlation length of the generated lognormal variable is $80\lambda_0$, where λ_0 is the wavelength. An example of a UE RACH transmission with mean transmitted power of 20 dBm is given in Fig. 3.

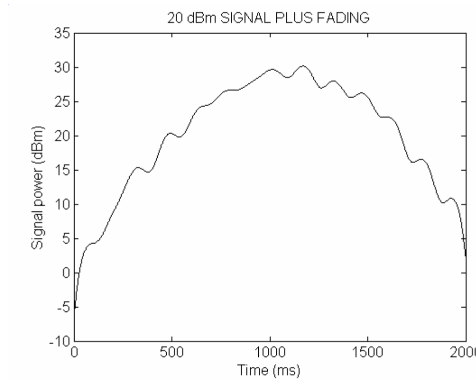

Figure 3. Example of fading suffered by a 20 dBm signal.

When the preamble is received, the SIR is calculated with actual values of uplink interferences and the preamble received power. If the SIR of the received preamble is higher than the SIR threshold and there is one free demodulator at least, the message transmission is granted. In performed simulations, the threshold of preamble SIR is set to –17 dB, that is a typical value. We suppose AICH indicators are error-free. In this paper, no radio access control is considered, so the unique reason for sending a NACK on AICH is the leak of available demodulators in the Node B RF unit. We assume three demodulators for RACH.

The message part is transmitted Δ_{PM} dB over the last preamble transmission level and with a spreading code determined by the signature of the last preamble. Due to preambles does not transport any user information, more than one UE using the same signature could be granted to transmit its message and will collide. We define the capture effect as the minimum SIR difference among the strongest message and the rest of messages to correctly detect the strongest one. In this paper, the capture effect is set to 4 dB. Before comparing the SIR of concurrent messages, in the simulator, messages with a mean SIR level below –19 dB are discarded and are computed as a failed access.

To evaluate the performance of a system with preamble power ramping, a single cell simulator is used. Users are uniformly located over the surface of a 750 m radius cell. We have only computed suscribers in Idle mode who establish an RRC connection or other mobility management operation through RACH. They only will demand to transmit one message. Therefore, RACH/FACH data users are not taken into account. In a real scenario, if we assume the arrival model is a Poisson process with λ as mean arrival rate, the input load due to signaling users is the addition of all the particular arrival rate of the considered UMTS services. Hence, for a single cell, a unique call generation rate should be considered, which should involve particular rates for each service (λ_i) and its penetration index. Typical UMTS traffic values lead the call generation rate for a single cell around 0.35 calls/second. The load is not sufficiently challenging and it is difficult to compare different simulation schemes since the differences in performance will be minimal. Thus, a Poisson load is proposed with a mean number of call attempts (λ) per 10 ms radio frame, among 1 and 5.

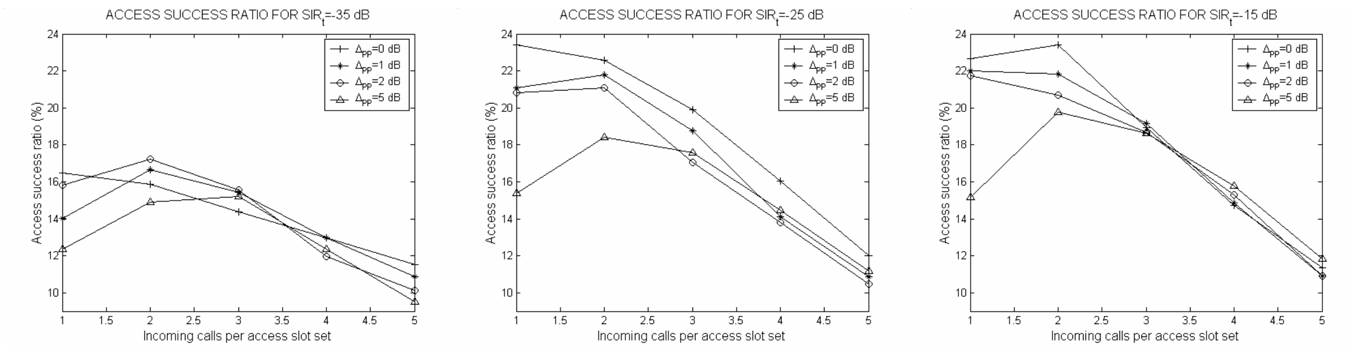

Figure 4. Random access success ratio for Δ_t=-35dB, -25dB and –15dB vs. average traffic load.

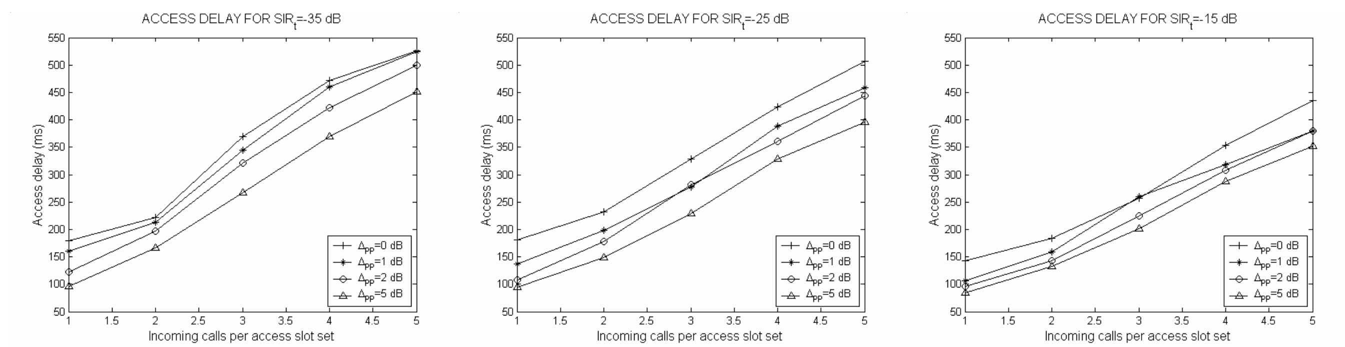

Figure 5. Random access delay for Δ_t=-35dB, -25dB and –15dB vs average traffic load.

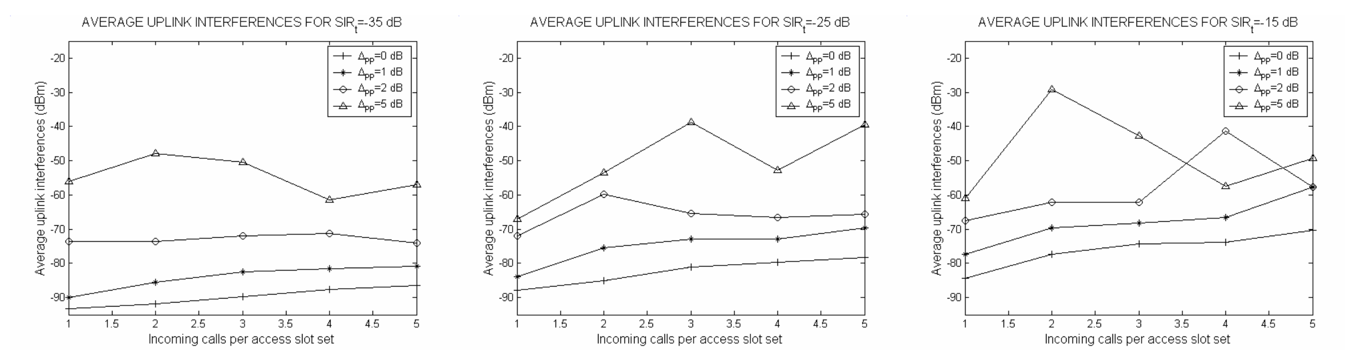

Figure 6. Average uplink interference level measured at Node B vs. average traffic load.

IV. SIMULATION RESULTS

In this section, the results of the simulations for the set of proposed radio parameters are discussed. The main indicators of RACH performance for signaling users are access delay and access success ratio. Simulations were developed to show the evolution of those indicators when the target SIR varies from –35 dB to –15 dB. For each case of SIR_t, four values of preamble ramping offset (Δ_{PP}) are proposed: 0 dB (no ramping), 1 dB, 2 dB and 5 dB. Furthermore, for each pair of (SIR_t, Δ_{PP}), the input calls are randomly generated with a Poisson distribution with mean λ calls per radio frame.

Users are uniformly located over the 750 m radius cell. The access success ratio measures the number of users that accomplishes not only the preamble transmission, but also the message transmission successfully, among the total generated users. For each call request, the total access delay is registered, note that only successful call attempts will compute in the RACH average access delay. The delay is measured between the born of a call attempt to the transmission of the last bit of the message. So, it involves the time necessary for randomly selecting the first access slot, the possible preamble retransmissions and the message part duration.

The results are obtained for a traffic class of one ASC, where all the RACH users try to transmit one message per user. As it is mentioned in section I, the associated resources for a given ASC are a set of sub-channels and a set of signatures. In simulations, there are 12 sub-channels and 16 signatures available (the total number of sub-channels and signatures).

The first effect that can be observed is the RACH performance worsening when the arrival rate is increased. The higher average rate is, the lower success ratio is, as Fig. 4 shows. According to the RACH success ratio, the worst target SIR is –35 dB. The open loop power control of the UE attempt to reach –35 dB SIR at the base station. Due to it is a low SIR level, the low transmitted power is masked by fading and preambles and messages are not correctly detected. When the target SIR becomes higher, the access success ratio is improved. The best result for access success is obtained for a target SIR of –15 dB. Inside this case, there are no relevant differences with Δ_{PP} variations.

Delay figures (Fig. 5) show the same result as success figures but in an inverse manner for Δ_{PP}. The worst access delays appear when a target SIR of –35 dB is used. The delay is reduced when SIR_t takes greater values.

In Fig. 6, the average level of uplink interferences measured at Node B side is presented. This level is the addition of the I_{floor} level (-95 dBm mean) plus the open loop RACH contribution. Here it could be observed that low traffic loads and low SIR_t cause lower interference levels. When SIR_t= -15dB, users transmit its preambles and messages with more power and generate more interferences.

If we compare the different results for Δ_{PP} within the same SIR_t simulations it could be seen that they area a trade off between access success ratio and delay. Ramping scheme with low power offset between preambles in proposed scenario produces less interferences than schemes with high power offsets. This is also obtained for the success ratio curves, but it has the inverse effect on delay results. As the same time those SIRt variations produce the same effect in access success than access delays (the performance is improved for high SIR_t values), the Δ_{PP} changes produce higher access success ratio for higher Δ_{PP} but lower access delays for lower Δ_{PP}.

In addition to delay curves, we observe for several simulations that when the traffic load is increased, the mean value of probability density function of the SIR of received preambles decreases and the gaussian deviation increases. The more users in the system are, the poor SIR is received and with more variability from the desired value of threshold SIR. An example of this result could be shown in Fig. 7, where it is represented the PDF of received preambles for the case of SIR_t=-15dB and Δ_{PP}=1dB.

V. CONCLUSIONS

Simulations yield a dual result in success ratio and delay indicators. It is demonstrated that higher values for SIR_t produce higher access success ratios and access delays. Nevertheless, as the parameter Δ_{PP} is increased the random access success ratio is reduced and the access delay is improved for the same SIR_t. Poor success ratios are related to uplink interference level as Fig 4 and 6 shows. The parameters entered in simulations such as SIR thresholds, fading deeps and interference addition lead poor performance results. For the set of simulated scenarios, best results are obtained with a target SIR of -15dB, and Δ_{PP}=1dB.

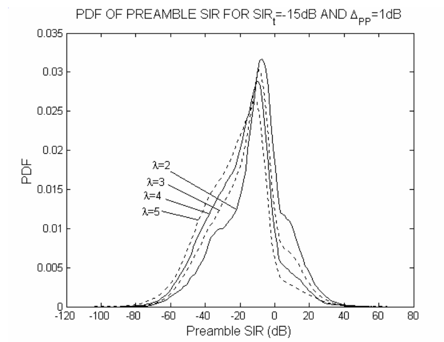

Figure 7. PDF of preamble SIR for Δ_t=-15dB and Δ_{PP}=1dB, for several input loads.

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