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Analysis of UMTS radio channel access delay

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Abstract

We present an analysis of delay encountered in successfully accessing the Random Access Channel (RACH) of Universal Mobile Telecommunication System (UMTS) Radio Interface by User Equipments (UE) that want to initiate data transfer. The process of random channel access is described and the MS state modeled as a DTMC in order to derive the delay. We evaluate the variation of the channel access delay with the preamble power, preamble detection threshold, maximum attempts, inter-attempt time interval, number of mobile users, number of slots, persistence level, rate of incoming data and rate of retransmissions. We also derive the capture probability of preambles sent in the same slot by multiple UEs in the presence of Rayleigh fading.

Keywords: UMTS; MAC; RACH delay; RACH throughput; Delay

1. Introduction

The radio interface of wireless networks poses a challenge for data transfer. Radio Interface delays affect the overall network performance to a great extent. Salkintzis et al. [11] have reported that in case of handoff, the delays involved in GPRS and UMTS networks form the bottleneck. In [2,13] the handoff delay is estimated using a break-up of all the delays caused during handoff, including both wireless and wireline delays of the networks involved. The wireless or radio interface delay would typically involve the channel access delay, resource allocation delay and data transfer delay. The channel access delay is a variable delay over the radio channel faced by every UE trying to access the network and has a direct impact on the response time of the UE. Therefore, we analyse the UMTS channel access delay.

The Medium Access Control (MAC) layer at the UMTS radio interface is based on slotted ALOHA mechanism. UEs that have data to transfer, send their resource request to the network on a common channel called Random Access Channel (RACH). A number of parameters like the dynamic persistence level, persistence scaling factor, maximum preamble retransmission cycles, maximum preamble ramp-up steps, the backoff range and inter-attempt spreading factor, broadcast as System Information messages, enable centralised, prioritized and fast access.

In the literature [6] shows that RACH access delay and error probability increases with increase in preamble arrival rate and decreases with increase in the number of RACH message part processing units. It shows by simulation that the overlapping Access Service Class (ASC) allocation method has better performance than the non-overlapping method. Ref. [9] shows the impact of preamble target Signal to Interference Ratio (SIR) value and power ramp-up step on the random access delay, success probability and uplink interference by means of simulation. The higher the SIR target, higher is the access success ratio and lesser the access delay. A high power ramp-up step leads to lesser delay but a lower access success ratio as it increases interference. When traffic load increases, the mean SIR of received preambles decreases and gaussian deviation increases due to increased interference level. Ref. [5] uses OpNet simulation for generating traffic on

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the RACH and shows that with small packet sizes the average access delay corresponds to the persistence value but with increased load and large packet size, delay is lower for smaller persistence values. Ref. [3] shows different mechanisms to introduce access priority, among which Random Backoff based access priority scheme is best in terms of access delay and throughput. Ref. [14] shows that linear and geometric ramping schemes are more effective than the fixed ramping scheme in increasing the success probability at the expense of high interference to existing traffic.

This paper presents an analysis of the variation of the UEs radio channel access delay with parameters like preamble power, preamble detection threshold, maximum attempts, inter-attempt time interval, number of mobile users, number of slots, persistence level, rate of incoming data and rate of retransmissions. The effect of one user and that of multiple users selecting the same slot on the delay is evaluated. The expression for capture probability of preambles being sent in the same slot by multiple UEs in the presence of Rayleigh fading is derived.

2. Delay modeling

In the access procedure the Physical RACH (PRACH) channel is used for sending a preamble, and the Acquisition Indicator Channel (AICH) carries acquisition indicators responding quickly to PRACH preambles. The PRACH access slots have 5120 chips per slot. Fifteen access slots occupy two radio frames of 20 ms total duration. A RACH preamble is of length 4096 chips, with spreading factor 256 and consists of 256 repetitions of a signature of length 16 chips. The RACH message part is like any other uplink 10 ms or 20 ms transmission consisting of a data part and a control part. With available spreading factors 32–256, the data part can support a data rate of 60 kbps to 7.5 kbps. The control part carries the pilot bits and Transport Format Combination Identifier (TFCI) bits [4].

Centralised probabilistic access control is performed individually for each PRACH through signalling of dynamic persistence levels that can be translated into class specific persistence probability values, p_i where $i = 0, 1, \ldots, 7$ and i is the Access Service Class (ASC).

$$p_0 = 1 \tag{1}$$

$$p_1 = 2^{-(N-1)}, \quad N = 1, \ldots, 8 \tag{2}$$

$$p_i = s_i p_1, \quad i = 2, \ldots, 7 \tag{3}$$

where N is the dynamic persistence level and $\{s_i = 0.2, \ldots, 0.9\}$ is the persistence scaling factor.

A cell may have up to 16 different PRACHs. PRACH resources are access slots and signatures. The access slots of a PRACH are split into 12 sub-channels. Every 12th access slot belongs to a specific PRACH sub-channel. More than one ASC or all ASCs can be assigned to the same access slot or signature space.

The access procedure can be broken into functionalities performed by the different layers. The Radio Resource Control (RRC) layer reads relevent information from BCCH and configures various parameters related to RACH access in the MAC and PHY layers. It also selects the PRACH, Transmission Time Interval (TTI) and Transport format (TF). The Medium Access Control (MAC) layer controls the timing of RACH transmissions on TTI level and Physical (PHY) layer controls the timing of RACH transmissions on access slot level.

2.1. Channel access delay

The model assumes that all UEs belong to the same Access Service Class and that all UEs' incoming data rates and retransmission rates are the same.

(1) Data arrives at the MAC layer of the UE at rate λ_d.
(2) MAC selects an ASC number i.
(3) It selects a random variable r between 0 and 1.
(4) If $r \leqslant p_i$, MAC sends the Transport Block (TB) to PHY layer for transmission on the PRACH.
(5) If $r > p_i$, MAC waits for a TTI before starting the persistency check again.
(6) PHY layer selects a RACH sub-channel and a signature. A combination of both is considered as a slot here.
(7) It determines the transmission power [16] and transmits the preamble on the PRACH.
(8) PHY layer checks the acknowledgement on the corresponding DL AICH signal.
(9) If positive acknowledgement, it informs MAC, gets the message part and transmits it on the PRACH after 3–4 slots depending on the AICH transmission timing parameter after setting the power correctly [16].
(10) If negative acknowledgement, it informs MAC. MAC starts a backoff timer and retries again, if its maximum retries are not exceeded.
(11) If no acknowledgement, it selects another slot, another signature, steps up the Preamble Transmission Power T_p^{PWR} by a power ramp-up step Δ_{p-p} and retransmits the preamble. If power limit or the number of retries is exceeded it stops and informs MAC.
(12) MAC retries in the next TTI till the maximum number of attempts are over. After that it stops the access and informs the higher layer.

The UE MAC layer functions during random access are modeled as a finite Discrete Time Markov Chain(DTMC) with two absorbing states, as shown in Fig. 1. D is the start state where UE has data to transmit. The UE starts channel access procedure with probability p_i and enters the first PHY layer action state PHY_0. With probability $1 - p_i$, it defers access and remains in state D. If the PHY layer returns success it forwards the message to PHY layer for transmission and goes to the absorbing state S_m denoting