Impact of Mobile-Originated Short Message Service on the Digital Control Channel of TDMA Systems

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Abstract

This paper evaluates the capacity of the ANSI-136 digital control channel (DCCH) uplink to carry high volumes of mobile-originated short message service (MO-SMS) traffic. The DCCH random access protocol is characterized and it is found that a random access channel (RACH) parameter setting of (10, 3, 4, 2) is optimum for providing good RACH performance. Simulation results indicate that the RACH has sufficient capacity to handle moderate levels of MO-SMS traffic. For cells with moderate and high levels of voice call traffic, it is found that the RACH can handle a MO-SMS traffic load of up to 1000 MO-SMS messages per hour without significantly affecting the performance of critical messages such as originations and page responses. It is found that when MO-SMS traffic levels exceed 1000 messages per hour, blocking rates of critical messages such as originations and page responses start rising, potentially affecting the quality of service experienced by the wireless customer.

1. Introduction

The Digital Control Channel (DCCH) is the primary backbone for providing paging, call-setup, broadcast and other control messaging for voice services on the ANSI-136 TDMA system. The DCCH also provides two-way short message service (SMS) through the R-DATA transport mechanism. This two-way SMS provides a limited data service that can be used for various applications such as telemetry and two-way alphanumeric messaging. SMS has seen a tremendous growth in Europe in the past year. For example, in the UK there has been a 900% increase in the number of SMS messages sent by mobile phone users over a period of one year [1]. SMS is also expected to grow strongly in the US. Since the DCCH is a limited resource whose primary purpose is to carry call setup and control messages, it is important to understand how it responds to increases in the level of SMS traffic. This is also evident from previously published studies ([2], [3]), which have analyzed different parts of this issue.

This paper presents a performance analysis of the uplink component of two-way SMS, known as mobile originated SMS (MO-SMS), showing its impact on the performance of the DCCH uplink. The paper begins in Section 2 by presenting an overview of the DCCH uplink, which is a random access channel (RACH) based on a slotted Aloha [4] type random access protocol. Section 3 describes the simulation testbed that was used to generate performance results. Section 4 is divided into two parts. The first part presents the characteristics of the DCCH random access protocol and derives optimum RACH protocol parameter settings. The second part presents RACH performance results for several levels of MO-SMS traffic. Note that voice call traffic contributes towards the number of messages carried on the DCCH uplink. Hence, the impact and performance of MO-SMS on the RACH is evaluated at moderate and high levels of voice call traffic. Section 5 concludes the paper.

2. DCCH Random Access Protocol

The RACH is a shared, unidirectional, point-to-point, acknowledged channel that is used by mobile stations (MSs) to communicate control information and short messages to the network. Thus, a MS transmits all registrations, originations, page responses, SPACH confirmations, R-DATA acknowledgements, and MO-SMS messages on the RACH.

The RACH is divided into six sub-channels or access paths (P1-P6) as shown in Figure 1. This sub-channeling serves two purposes. It allows for sufficient processing time at the base station (BS) and the MS, and provides six independent paths for MSs to access the DCCH.

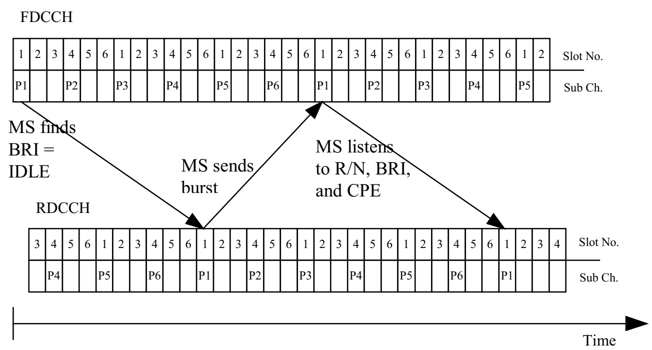

Figure 1. RACH Operation

The BS provides feedback to all MS accesses on the RACH via the Shared Channel Feedback (SCF) fields on the downlink. The SCF consists of the Received / Not Received (R/N) word, the Busy / Reserved / Idle (BRI) word, and the Coded Partial Echo (CPE) word. The R/N word tells the MS whether its uplink burst was correctly received or not. The BRI word broadcasts the status of the next uplink slot on the corresponding access path. The CPE field is used to identify the MS that has captured the corresponding access path.

When a MS decides to send a message on the RACH, it starts listening to the SCF on the Forward DCCH (FDCCH) and waits for BRI=IDLE. If the MS finds BRI=IDLE on sub-channel P1 as shown in Figure 1, then it transmits its burst 64.8 msecs later in the corresponding P1 slot on the uplink. After transmitting its burst, the MS waits 41.8 msecs before it starts listening for feedback from the BS on the corresponding P1 slot on the FDCCH. If the BS is able to capture the MS's burst successfully, then it sets the R/N field to R and the CPE field to the MS's CPE indicating to the MS that its access on sub-channel P1 was captured successfully.

The ANSI-136 standard defines a random access protocol that all compliant MSs have to follow while accessing the RACH. This RACH protocol was designed to make channel utilization of the RACH as efficient as possible. It is based on the slotted Aloha protocol, whose throughput, S, is defined by the equation,

$$S = Ge^{-G},$$

where G is the rate of offered traffic. The theoretical maximum throughput of a slotted Aloha channel is 38.6% [4].

The performance of slotted Aloha assumes that all transmitted messages have a length equal to one slot. Even though most messages on the DCCH are one slot in length, there are some messages, such as originations and SMS messages, which are longer than one slot. For messages that are longer than one slot, the first slot is transmitted using random access. But for subsequent slots, the RACH protocol provides a form of reservation access based on the SCF. Due to this reason the performance of the RACH protocol may be slightly better than that of a true slotted Aloha protocol.

The RACH random access protocol uses five counters: the Busy/Reserved counter, the Retry counter, the Repetitions counter, the Stop counter, and the Burst counter. The first four of these counters have maximum limits that can be specified by the operator within the ranges defined in Table 1.

Table 1. Random Access Parameters

RACH Parameter	Range
Max Busy/Reserved	1 or 10
Max Retries	1 to 8
Max Repetitions	1 to 4
Max Stops	1 or 2

The Max Busy/Reserved parameter defines the maximum number of busy or reserved slots that a MS seeking random access should wait before declaring an access attempt failure. The Max Retries parameter defines the maximum number of access attempts a MS should make before declaring an access failure. The Max Repetitions parameter defines the maximum number of times a MS should try to retransmit a failed burst before declaring an access attempt failure. The Max Stops parameter determines the maximum consecutive instances of one of the following two conditions that a MS should detect before declaring an access attempt failure: BRI ≠ Busy after sending an intermediate burst of an access attempt; or R/N = Not Received and BRI ≠ Busy after sending the last burst of an access attempt. The default settings of these random access parameters are given in Table 1. Results presented in Section 4.1 will show how RACH performance changes as a function of these parameters.

3. Simulation Testbed

A DCCH uplink simulation testbed that simulates the RACH protocol has been created using the BONeS Designer™ software package. As shown in an overview of the testbed in Figure 2, each MS has a set of message generators, a MO-SMS ARQ engine, and a block that implements the MS-side RACH protocol. The rates of these message generators are set such that the overall message load on the RACH corresponds to the load at which the RACH performance is to be evaluated.

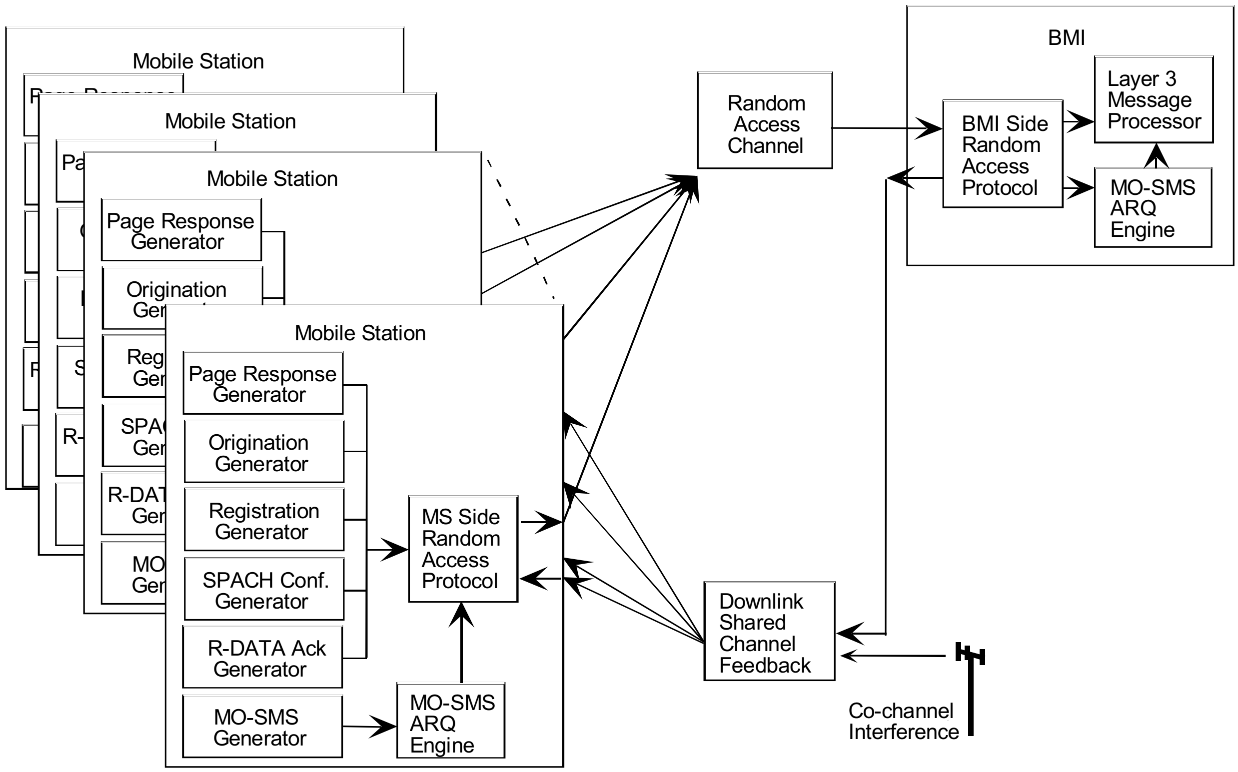

Figure 2. DCCH Uplink Simulation Testbed

Since the RACH is a shared random access channel, multiple MSs may detect an idle slot and may try to transmit bursts in the same slot. In such a situation, the signal strengths of the MSs competing for successful transmission are used to determine whether any of the transmitted bursts is received successfully. MSs are assumed to be uniformly distributed across the serving sector. A simple path loss exponent propagation model is assumed with a path loss exponent of 3.7 dB. Lognormal shadowing with a standard deviation of 6 dB is assumed. The cell radius is assumed to be 3 km.

Based on the above assumptions, cumulative distribution functions (CDFs) of received signal strength (RSS) and C/I ratio are generated using simulations. Each MS trying to transmit a message on the uplink is dynamically assigned a signal strength value from the RSS CDF. If there are N MSs trying to transmit a burst in a given slot, the MS with the highest received signal strength, RSS_H dBm, is treated as the signal to be captured at the BS. The received signal strength, RSS_x dBm *;* $x=1,\ldots,N-1$, of all the other MSs trying to successfully transmit a burst in the same slot adds up as interference to the MS with the highest RSS. In addition to this interference, there may be co-channel interference from a MS that is using the same channel in another cell, whose received signal strength in dBm can be denoted as RSS_{coch}. Thus, the total signal to interference ratio in dB seen by the MS with the highest RSS can be written as,

$$\frac{C}{I} = RSS_H - \left\{10 \times \log_{10}\left[\left(\sum_{x=1}^{N-1} 10^{(RSS_x/10)}\right) + 10^{(RSS_{coch}/10)}\right]\right\} \; dB.$$

Once the level of interference seen by the MS with the highest RSS is determined, the probability of its signal being successfully captured by the BS is determined from the RACH capture probability curve shown in Figure 3, which is generated from physical layer simulations of the RACH. If the BS captures the burst based on this probability, it sets the appropriate fields on the downlink to provide feedback to all the MSs about the result of their access attempts. The downlink feedback channel is assumed to have errors corresponding to a C/I level of 21 dB.

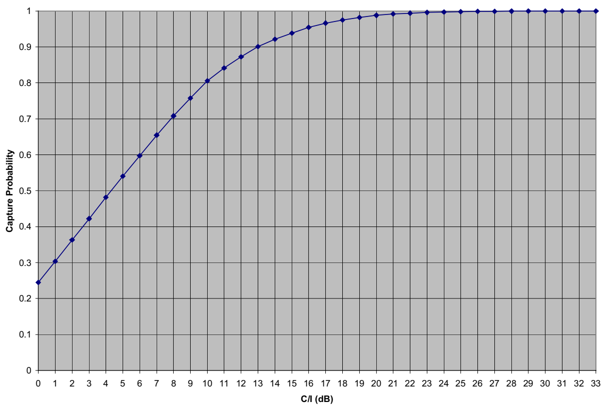

Figure 3. RACH Capture Probability (40 km/h, 836.5 MHz)

4. Results

Results are presented in two parts. Section 4.1 presents the sensitivity of RACH throughput, occupancy, and blocking rate with respect to different values of the four RACH parameters given in Table 1. Section 4.2 presents the performance of MO-SMS based on optimum RACH parameter settings found in Section 4.1.

4.1 Characterization of RACH Performance

The RACH protocol is based on a modified slotted Aloha protocol. However, based on values of the RACH parameters, a MS with a failed access attempt can come back after a brief waiting period to retry the access attempt. This type of behavior may cause the RACH protocol performance to differ from that of slotted Aloha. Among the four RACH parameters given in Table 1, it is found that RACH performance is most sensitive to the setting of the Max Retries parameter. This section compares the RACH performance for the following five settings of the RACH parameters (Max Busy/Rsvd, Max Retries, Max Reps, Max Stops):

- the minimum allowed values (1, 1, 1, 1);
- (10, 1, 4, 2) corresponding to Max Retries = 1;
- (10, 2, 4, 2) corresponding to Max Retries = 2.
- (10, 3, 4, 2) corresponding to Max Retries = 3;
- (10, 8, 4, 2) corresponding to Max Retries = 8.

All messages are assumed to be one slot in length.

Figure 4 shows percentage RACH throughput for message arrival rates ranging from 1 message per second to 400 messages per second. The (1, 1, 1, 1) curve exhibits the classic slotted Aloha behavior with the throughput increasing steadily up to a certain level of load, after which it starts decreasing. This decrease in throughput is caused because of more and more access attempt failures due to collisions.

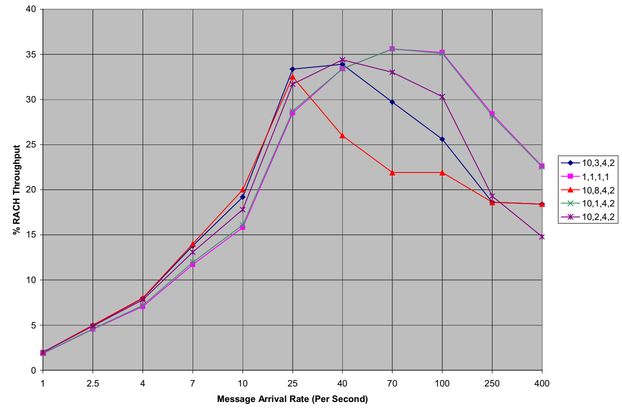

Figure 4. RACH Throughput Characteristics

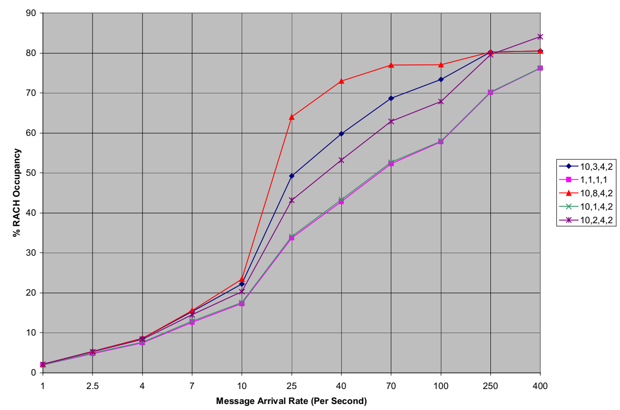

Figure 5. RACH Occupancy Characteristics

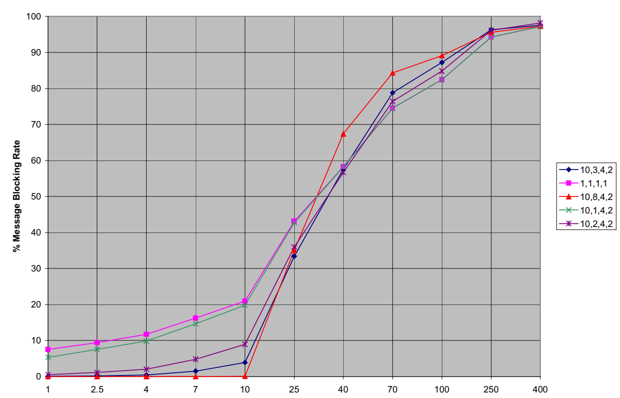

Figure 6. RACH Blocking Rate Characteristics

The (10, 3, 4, 2) throughput curve has a lower peak throughput than the (1, 1, 1, 1) throughput curve and reaches a knee at a lower message arrival rate. The percentage RACH occupancy curve shown in Figure 5 shows the RACH running at a higher (worse) RACH occupancy for the (10, 3, 4, 2) case than for the (1, 1, 1,

1) case. This is because for the (1, 1, 1, 1) case, no access attempt retries are allowed and MSs with failed attempts never come back to retry. For the (10, 3, 4, 2) case, MSs with failed access attempts come back after a brief waiting period to retry their access attempts, thus adding to the load on the channel. This causes the (10, 3, 4, 2) curve to reach a throughput knee at a lower message arrival rate than the (1, 1, 1, 1) case, also causing it to have a lower peak throughput and a higher RACH occupancy level.

Referring back to Figure 4, when the Max Retries parameter is set to 8, the (10, 8, 4, 2) curve shows that throughput is cut back significantly due to the higher number of retries. In Figure 5, the (10, 8, 4, 2) curve shows the highest RACH occupancy due to the same reason. Note that there is very little difference between the (1, 1, 1, 1) curve and the (10, 1, 4, 2) curve in Figures 4 and 5 indicating that the Max Busy/Reserved, Max Repetitions, and Max Stops parameters do not significantly affect the RACH performance.

Figures 4 and 5 seem to indicate that the (1, 1, 1, 1) setting has the highest throughput and lowest RACH occupancy levels. But as the Max Retries parameter is increased from 1 to 8, the throughput performance steadily becomes worse and the RACH occupancy level goes higher and higher.

While Figure 4 indicated that the (1, 1, 1, 1) case had the highest throughput performance, Figure 6 shows that the (1, 1, 1, 1) case has the worst blocking rates. Since there are no retries in the (1, 1, 1, 1) case, the blocking rate is as high as 10% even for relatively low RACH loads. Such a blocking rate would be unacceptable in a real system. When the Max Retries parameter is increased from 1 to 8, the blocking rate goes lower and lower, with the (10, 8, 4, 2) case having the lowest blocking rate.

Thus, the optimum setting for the RACH parameters has to be a compromise between the throughput performance shown in Figure 4 and the blocking rates shown in Figure 6. It is found that the RACH parameter setting of (10, 3, 4, 2) offers a good compromise solution and should be chosen as the optimum setting for good RACH operation.

4.2 Performance of MO-SMS

This section presents MO-SMS performance results for the optimum RACH parameters selected in Section 4.1. Since the DCCH uplink is a random access channel, messages from all MSs have an equal priority. This means that a MS that is trying to send a voice call page response gets the same priority as a MS that is trying to send a short message. So an increase in the level of SMS traffic can potentially affect the blocking rate on voice calls, and vice versa. In this study MO-SMS performance is evaluated for moderate and high levels of voice call traffic. The MO-SMS messages are assumed to range in length from 30 to 65 octets, which corresponds to 3 to 6 slots on the uplink. The RACH capacity is evaluated at several levels of MO-SMS traffic ranging from 10 to 10000 MO-SMS messages per busy hour per DCCH.

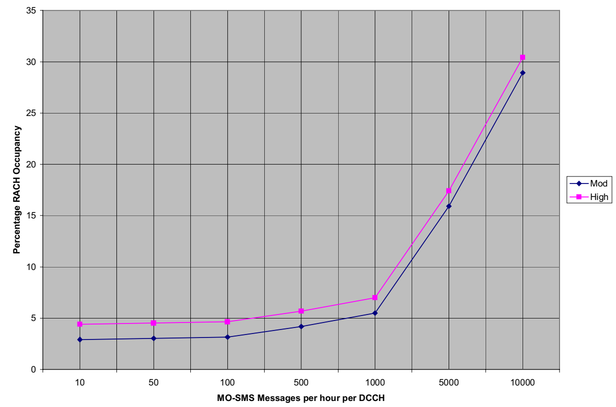

Figure 7. RACH Occupancy

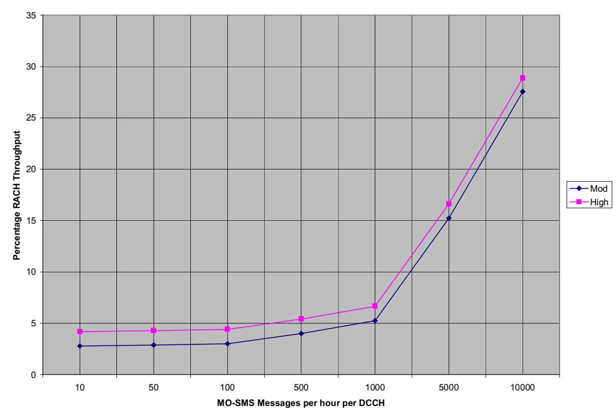

Figure 8. RACH Throughput

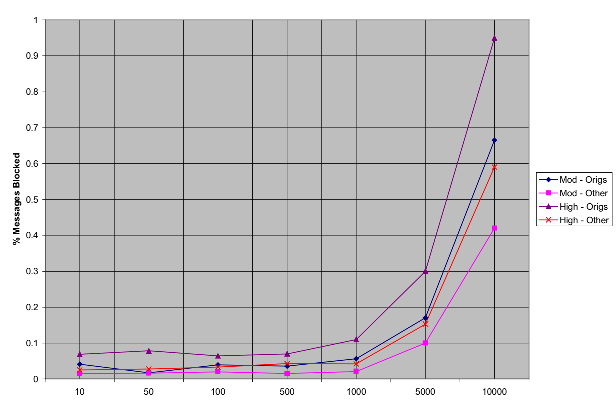

Figure 9. RACH Blocking Rates

Figures 7 and 8 show percentage RACH occupancy and throughput versus number of MO-SMS messages per hour. It can be observed that the average RACH occupancy in Figure 7 rises at a low rate till MO-SMS traffic reaches 1000 messages per hour, after which it rises rapidly. At 10000 messages per hour, the RACH throughput in Figure 8 starts approaching the 30% mark, which is just below the peak throughput level for the RACH protocol shown in Figure 4 in Section 4.1. This means that at a load of 10000 MO-SMS messages per hour with a high level of voice call traffic, the RACH is being pushed almost up to its peak throughput limit.

Since there are no message priorities on the RACH, all messages are treated equally. Hence, an increase in MO-SMS traffic could have an impact on the blocking rates of other more important messages such as page responses and originations. Figure 9 presents the impact of MO-SMS traffic on the blocking rate performance of originations, which are two slots in length, and other messages, which are one slot in length (registrations, page responses, SPACH confirmations, and R-DATA acknowledgements). It can be observed that MO-SMS traffic has little impact on the blocking rates of messages for both the moderate and high voice call traffic cases until a level of 1000 MO-SMS messages per hour is reached. After that, the blocking rates start rising steadily, and for the high voice call traffic case they reach nearly 1% for originations and 0.6% for registrations, page responses, etc. at the 10000 MO-SMS messages per hour level.

Figures 10 and 11 present 95-percentile message delays for moderate and high levels of voice call traffic with MO-SMS traffic ranging from 10 to 10000 MO-SMS messages per busy hour. Note that these delays are over the air interface and do not include any network delays. Figures 10 and 11 indicate that there is relatively little impact of MO-SMS traffic on RACH performance up to a level of 1000 messages per hour. Message delays remain relatively unchanged till 1000 MO-SMS messages per hour, after which they start rising gradually.

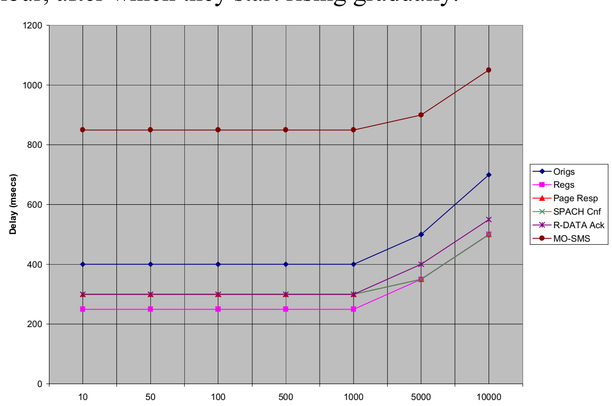

Figure 10. 95-Percentile Message Delay - Moderate Call Traffic

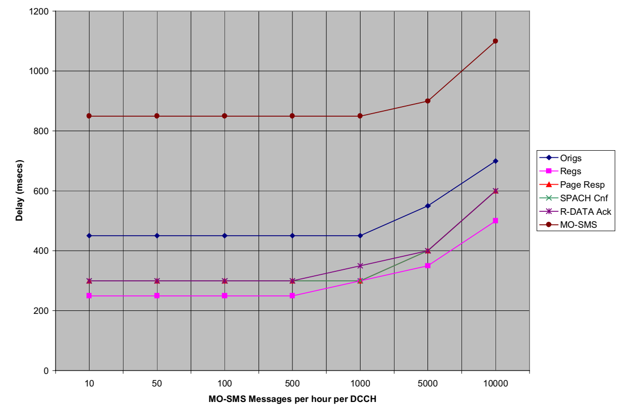

Figure 11. 95-Percentile Message Delay - High Call Traffic

5. Conclusions

This paper evaluates the capacity of the ANSI-136 DCCH uplink to carry high volumes of MO-SMS traffic under moderate and high levels of voice call traffic.

The DCCH random access protocol is characterized and it is found that a RACH parameter setting of (10, 3, 4, 2) is optimum for providing good RACH performance.

Simulation results indicate that the RACH has sufficient capacity to handle moderate levels of MO-SMS traffic. For cells with moderate and high levels of voice call traffic, it is found that the RACH can handle a MO-SMS traffic load of up to 1000 MO-SMS messages per hour without significantly affecting the performance of critical messages such as originations and page responses. It is found that when MO-SMS traffic levels exceed 1000 messages per hour, blocking rates of critical messages such as originations and page responses start rising, potentially affecting the quality of service experienced by the wireless customer.

6. References

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