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An Alternative Resource Sharing Scheme for Land Mobile Satellite Services

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Abstract

This paper presents a preliminary comparison between the two competing channelization concepts for the Land Mobile Satellite Services (LMSS), namely frequency division (FD) and code division (CD). Both random access and demand-assigned approaches are considered under these concepts. The CD concept is compared with the traditional FD concept based on the system consideration and a projected traffic model. It can be seen that CD is not particularly attractive for the first generation Mobile Satellite Services because of the spectral occupancy of the network bandwidth. However, the CD concept is a viable alternative for future systems such as the personal access satellite system (PASS) in the Ka-band spectrum where spectral efficiency is not of prime concern. The effects of power robbing and voice activity factor are incorporated. It has been shown that the traditional rule of thumb of dividing the number of raw channels by the voice activity factor to obtain the effective number of channels is only valid asymptotically as the aggregated traffic approaches infinity.

1 Introduction

In 1983 the Jet Propulsion Laboratory (JPL), as lead center for the National Aeronautics and Space Administration (NASA)'s Mobile Satellite Program, selected to follow the frequency division (FD) concept for the Mobile Satellite Experiment (MSAT-X) project. One of the main system considerations was to offer low cost terminals to the general subscribers. The concept of code division (CD) was discussed but was not pursued because of the cost and maturity of the technology for mobile applications.

1.1 Resource Sharing Approaches

There are two basic approaches to utilize these two channelization concepts. One is the random access approach whereby each subscriber is allowed to transmit without making explicit requests to a Network Control Center (NCC). The other one is the demand-assigned approach. Each subscriber must make a connection request known to the NCC before a transmission is granted. In MSAT-X, an Integrated-Adaptive Mobile Access Protocol (I-AMAP) governs the operations of subscribers accessing the network. It is an example of the demand-assigned approach using the FD concept. The protocol consists of the channel access protocol and the connection protocol. The channel access protocol is identical to the random access approach without the NCC. The prime objective of using I-AMAP was to maximize the number of subscribers for the first generation Mobile Satellite Services (MSS).

On May 31, 1989, The Federal Communications Commission (FCC) granted the MSS license to the American Mobile Satellite Corporation (AMSC). It is very likely that AMSC will adopt the FD concept for the first generation MSS. Advanced technologies developed under MSAT-X might be transferred to AMSC.

Ideally, I-AMAP which is a generic protocol is independent of the channelization technique. Results derived for the MSAT-X therefore can be directly applied to predict the performance of the CD network using the I-AMAP under certain conditions. The differences lie in the hardware implementation between these two concepts and the throughput of the random access technique in making connection requests.

This paper provides a preliminary analysis between these two competing concepts for the MSS from a different perspective. Previous discussions compare the performance of these two concepts based on the satellite operating characteristics [1, 2]. Recently the joint Qualcomm/PacTel experiment demonstrated the feasibility of adopting CD concept for the cellular radio environment. The concept of CD emerges as a promising candidate for designing future MSS.

1.2 Impacts of Voice Activity

During a conversation, the gaps between talk spurs can be exploited to maximize the utility of satellite resources. The voice activity factor increases the effective number of voice channels. Because the voice activity is statistical in nature, the possibility of satellite overloading exists. Overloading occurs when the number of voice packets arriving at the satellite from different active subscribers exceeds the threshold value, beyond which the satellite will no longer be able to provide adequate power amplification for each channel. Overloading can result in performance degradation, i.e., increased bit error rate (BER) and packet errors, and lower voice quality. In case of mixed voice and data traffic, overloading can result in increased data packet errors and retransmissions. The extent of degradation depends on the link characteristics and is severer for downlink limited channels. This paper examines the probability of overloading and the resulting degradation for voice only traffic. Typical parameter values are based on the current personal access satellite system (PASS) design. Results will be used to establish the margin (TWT backoff) needed to meet the reliability requirement.

For systems following the CD concept, the statistical nature of voice activity also causes the self-noise level to vary accordingly. This factor should be considered in system design. In this analysis, this effect is ignored.

Section 2 describes the impact on system performance due to voice activity factor, or commonly known as the VOX factor, for FD under the demand-assigned approach. Section 3 describes the effect of VOX on the CD concept. Section 4 relates the overloading probability with the satellite transponder margin to meet the reliability requirement. Section 5 presents a framework to compute the throughput of a CD network under the random access approach. Section 6 provides a summary.

2 Effect of VOX on FD Architecture

Let B be the available bandwidth and W be the channel spacing for a FD architecture under the demand-assigned approach. For voice application, the effect of the channel access protocol operated on request channels can be ignored. Without loss of generality, the total number of available channels, N_t, can be written as $N_t = \frac{B}{W}$. In practice, the available satellite power may not be able to support all N_t channels. Let P be the total RF power and P_f be the power required to achieve the bit error rate of γ_f per FD channel. We made a simplified assumption that the channel will be error-free whenever the power exceeds P_f. The number of channels available under the power constraint is then given by $N_p^{(f)} = \frac{P}{P_f}$. In general $N_p^{(f)} < N_t$ represents a power limited satellite, and $N_t < N_p^{(f)}$ represents a bandwidth limited satellite.

Let λ be the aggregated average call arrival rate and $(\frac{1}{\mu})$ be the average call duration. (μ is the average service rate per call.) If the satellite is bandwidth limited, for any given blocking probability α_f and N_t, the scenario can be modeled by a $M/M/N_t/N_t$ queuing model under the Poisson assumption. The aggregated traffic that can be supported is given by the well known Erlang-B formula,

$$\alpha_f = \frac{\rho^{N_t} \frac{1}{N_t!}}{\sum_{k=0}^{N_t} \rho^k \frac{1}{k!}} \quad (1)$$

where $\rho = \frac{\lambda}{\mu}$.

Equation (1) does not consider that at least half of the time either party is listening rather than talking. If the satellite is bandwidth limited, we can not take advantage of the gaps between talk spurs. However, in a power limited satellite, since $N_p^{(f)} < N_t$, the maximum number of channels that carries the conversation is smaller than the available number of channels N_t. During the silence period of a conversation, the available satellite power P_f can support additional channels. In this paper, we consider the case of only power limited satellites.

Consider the same queuing model that the call service rate is increased by a factor of ν. This corresponds to a VOX factor of $(\frac{1}{\nu})$. For a power limited satellite, the probability that an incoming call will be blocked for a given $N_p^{(f)}$ is the probability that a call will overload the satellite.

Let N_r be the number of channels required for any given ρ and δ_0 be the desired overloading probability. Then

$$\delta_0 = \frac{(\frac{\rho}{\nu})^{N_r} \frac{1}{N_r!}}{\sum_{k=0}^{N_r} (\frac{\rho}{\nu})^k \frac{1}{k!}}. \tag{2}$$

Note that the total satellite power required is $N_r P_f$. If the resulting $N_r < N_p^{(f)}$, the satellite has sufficient power to support all N_r channels without even considering the VOX factor. A more interesting case is when $N_r > N_p^{(f)}$.

Let

$$\beta = 1 - \frac{N_r}{N_s} \tag{3}$$

where N_s is the number of channels without the VOX factor (i.e. $\nu = 1$). Table 1 shows the percentage of improvement due to VOX factor of 50% for an overloading probability of 5%. Tables 2 and 3 show the corresponding improvement for 1% and 0.1%. It is interesting to observe that as the traffic increases, the improvement due to VOX approaches a limit. Specifically, let

$$\delta_0 = \frac{(\frac{\rho}{\nu})^{N_r} \frac{1}{N_r!}}{\sum_{k=0}^{N_r} (\frac{\rho}{\nu})^k \frac{1}{k!}} = \frac{\rho^{N_s} \frac{1}{N_s!}}{\sum_{k=0}^{N_s} \rho^k \frac{1}{k!}}. \tag{4}$$

As ρ increases, the summations of both denominators are dominated by the last two terms. From (4), for large enough ρ,

$$\frac{(\frac{\rho}{\nu})^{N_r} \frac{1}{N_r!}}{(\frac{\rho}{\nu})^{N_r} \frac{1}{N_r!} + (\frac{\rho}{\nu})^{N_r-1} \frac{1}{(N_r-1)!}} = \frac{\rho^{N_s} \frac{1}{N_s!}}{\rho^{N_s} \frac{1}{N_s!} + \rho^{N_s-1} \frac{1}{(N_s-1)!}}. \tag{5}$$

Rearranging terms in (5), we have

$$\lim_{\rho \to \infty} \left(\frac{N_s}{N_r} \right) = \nu \tag{6}$$

Figure 1 shows the percentage of improvement due to the VOX factor for various traffic conditions. From Figure 1, it can be seen that the improvement due to the VOX factor approaches a limit as predicted by (6). The usual rule of thumb of dividing the number of raw channels by the VOX factor to obtain the effective number of channels is only asymptotically true for heavy traffic conditions. The fluctuation at low traffic levels is due to the integral values of the number of channels.

Traffic	Number of Channels		(β)% of
(Erlangs)	w/o VOX	w/ VOX	Improvement
1.0	4	3	25.0
11.0	16	10	37.5
21.0	27	15	44.4
31.0	37	21	43.2
41.0	47	26	44.7
51.0	57	31	45.6
61.0	67	36	46.3
71.0	77	41	46.8
81.0	87	46	47.1
91.0	96	51	46.9
101.0	106	56	47.2
111.0	116	61	47.4
121.0	126	66	47.6
131.0	135	71	47.4

Table 1: Performance Improvement due to VOX of 50% and $\delta_0 = 5\%$

Traffic	Number of Channels		(β) % of
(Erlangs)	w/o VOX	w/ VOX	Improvement
1.0	5	4	20.0
11.0	19	12	36.8
21.0	31	19	38.7
31.0	43	25	41.9
41.0	54	31	42.6
51.0	65	36	44.6
61.0	76	42	44.7
71.0	87	48	44.8
81.0	97	53	45.4
91.0	108	59	45.4
101.0	118	64	45.8
111.0	129	70	45.8
121.0	139	75	45.7
131.0	150	81	46.0

Table 2: Performance Improvement due to VOX of 50% and $\delta_0 = 1\%$

Traffic (Erlangs)	Number of Channels w/o VOX	Number of Channels w/ VOX	(β) % of Improvement
1.0	6	5	16.7
11.0	23	15	34.8
21.0	36	22	38.9
31.0	49	29	40.8
41.0	61	35	42.6
51.0	73	42	42.5
61.0	84	48	42.9
71.0	96	54	43.8
81.0	107	60	43.9
91.0	118	66	44.1
101.0	129	72	44.2
111.0	141	78	44.7
121.0	152	84	44.7
131.0	163	89	45.4

Table 3: Performance Improvement due to VOX of 50% and $\delta_0 = 0.1\%$

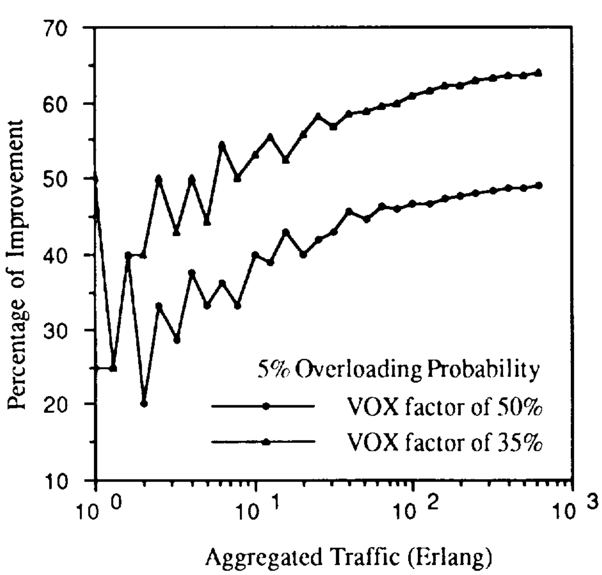

Figure 1: Performance Improvement due to VOX factor for various traffic loading

3 Effect of VOX on CD Architecture

Now, consider the case of a CD architecture. Let P_c be the power required to achieve the bit error rate of γ_c per CD channel. We made a simplified assumption that the channel will be error-free whenever the power exceeds P_c. The number of channels available under the power constraint is then given by $N_p^{(c)} = \frac{P}{P_c}$. Unlike the FD concept, the maximum number of communications channels is solely determined by the quantity $N_p^{(c)}$. Under the demand-assigned approach, we can make a simplified assumption that the NCC controls the number of requests. In this case, the scenario operated under CD concept is similar to the FD architecture. Results developed in the previous section are valid for the CD concept under the demand-assigned approach.

4 Performance Degradation

This section relates the overloading probability to the required link margin (or degradation) for a given satellite transponder design point. If the link is limited by uplink thermal noise, overloading effect can be negligible. On the other hand, if the link is severely limited by downlink thermal noise, overloading can cause significant degradation. Figure 2 shows the degradation of $\frac{C}{N_0}$, $\Delta_{\frac{C}{N_0}}$, in dB as a function of per channel downlink power normalized to the design point value. Results in Figure 2 are parameterized by η, where η is the ratio of downlink thermal noise to uplink thermal noise at design point. It should be noted that the satellite traveling wave tube (TWT) is assumed to be operating at constant output power in order to examine the impacts of voice activities. Effects such as interference and other channel impairments are ignored.

Table 4 relates the overloading probability with the degradation $\Delta_{\frac{C}{N_0}}$ for a fixed design point as a function of η for two traffic scenarios: high traffic (101 erlangs) and low traffic (21 erlangs). Results in Table 4 are computed for the case with VOX and the satellite TWT sized for a fixed operating point corresponding to 5% overloading probability. Degradations of $\frac{C}{N_0}$ are calculated as the overloading probability changes from 5% to 1% to 0.1%. (In other words, system availability increases from 95% to 99% to 99.9% as shown in Table 4.) Entries in Table 4 for system availabilities of 99% and 99.9% are based on Tables 2

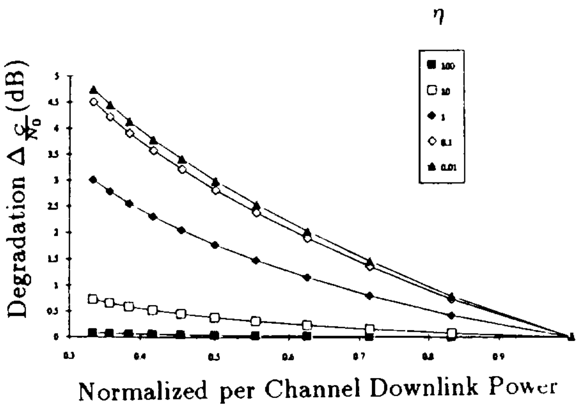

Figure 2: Degradation on the total $\frac{C}{N_0}$

and 3. As expected, the degradation is more severe for low traffic systems. Based on the table, in order to achieve a high system availability (99.9%), a margin of about 2 dB is necessary for low traffic and downlink limited systems. For uplink limited systems, the degradation is negligible. For the case without VOX, lowering the overloading probability from 5% to 1% does not, in practice, result in performance degradation.

5 Throughput of Random Access CD Network

Both CD and FD concepts can be utilized under the random access approach. This section provides a framework to evaluate the throughput of the CD network under the random access approach. It has been suggested [3] that a CD network should be operated at about 10% of the total network bandwidth for reasonable error performances without specific coding techniques. This observation was supported by Xiang [4] in his detailed computation of the maximum number of subscribers for non-coherent-phase CDMA at BER of 10^{-3} for non-fading channels. In [5], the maximum throughput for CDMA was derived for convolutional coded systems. Later papers concentrated on calculating the bit error and packet error performance for different combinations of modulation and spreading techniques on various transmission conditions [6, 7]. In [8], the throughput of a slotted random access CDMA system was derived under the Poisson arrival model. This paper includes the voice activity in the model by incorporating a parameter ν as discussed in Section 2.

We assume a slotted system where the arrival process is Poisson with an average aggregated arrival rate λ_c. Each subscriber transmits a packet of fixed length L. Let $P_c(m)$ be the probability of correctly receiving a packet from a designated subscriber, given that there are $(m-1)$ other simultaneous transmissions. Let $\mathcal{S}$ be the throughput (packets/slot) of the random access CDMA system. Using the voice activity model described in Section 2, the throughput is given by

$$\mathcal{S} = \rho_e e^{-\rho_e} \sum_{m=0}^{\infty} \frac{\rho_e^m}{m!} P_c(m+1), \qquad (7)$$

where $\rho_e = \frac{\rho_c}{\nu}$ is the effective traffic and $\frac{1}{\nu}$ is defined in Section 2. The quantity $\rho_c = \lambda_c T$ represents the aggregated traffic per slot, where T is the slot size. The average number of retransmissions is given by

$$r_{av} = \frac{\rho_e}{\mathcal{S}} - 1.$$

Equation (7) represents a generic expression which relates the throughput of a CD network with the modulation and spreading technique. Once the probabilities of $P_c(m)$ are specified, the throughput of the CDMA system can be determined. The computation of $P_c(m)$ for a specific CDMA system is quite involved and is beyond the scope of this paper. In the following, we demonstrate the computation using (7) by three examples. Example 1 and example 2 illustrate two bounding conditions for a random access CD system. Example 3 shows the throughput of a sample CD system under the random access approach.

Example 1. Let $P_c(1) = 1$, $P_c(m) = 0$ for $m \geq 2$, and $\nu = 1$. This corresponds to a slotted ALOHA system without considering the advantage of the VOX factor under the CD concept. From (7), the throughput is given by

$$\mathcal{S} = \rho_c e^{-\rho_c}.$$

Example 2. Let $P_c(m) = 1$ for all m, and $\nu = 1$. This corresponds to a perfect system with arbitrary number of CD channels without the VOX factor. The throughput is therefore ρ_c.

Example 3. Consider a binary direct-sequence spread spectrum system with random code sequences. Lehnert and Pursley [6] have provided the upper and lower bounds for the bit error probability. They also compared the performance with the Gaussian approx-

η	Degradation $\Delta_{\frac{C}{N_0}}$(dB) for selected system availability and traffic				Comments
	21 Erlangs		101 Erlangs		
	99%	99.9%	99%	99.9%	
$\frac{1}{100}$	1.0	1.7	0.6	1.1	extremely downlink limited case
$\frac{1}{10}$	0.9	1.5	0.5	1.0	downlink limited case
1	0.5	0.9	0.3	0.6	equal uplink and downlink noise
10	0.1	0.2	0.1	0.1	uplink limited case
100	0	0	0	0	extremely uplink limited case

Table 4: Degradation of Total $\frac{C}{N_0}$ based on 5% Overloading Probability Design Point

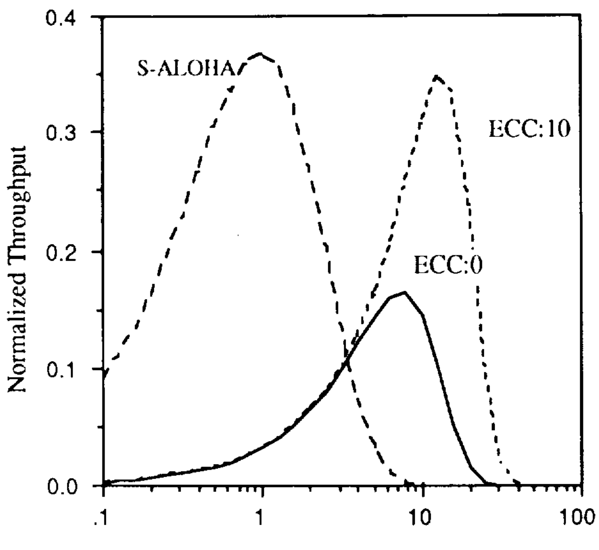

Figure 3: Normalized Throughput of the sample CD network in Example 3

imation. In [7], it has been shown that the Gaussian approximation is accurate only when there are a large number of simultaneous subscribers on the channel; otherwise the approximation can be optimistic by several orders of magnitude. They computed the average probability of packet error versus the number of subscribers. Table 5 gives the $P_e(m)$ versus m. In Table 5, number of chips per data bit is 31, packet length is 1000 including the error correction bits. The error correction capability of the code is assumed to be 10. In Figure 3, the normalized throughput of this CDMA system is denoted by ECC:10. Also in Figure 3, we include the case of no error correction capability for comparison. Notice that the vertical axis of Figure 3 is normalized by the bandwidth expansion of the sample CD network.

Figure 3 shows that, for this sample CD network, the maximum throughput is smaller than that of the classical S-ALOHA network. In case of no error correction capability (ECC:0 in Figure 3), the maximum throughput is less than half of that of the S-ALOHA network. The maximum throughput of 0.35 packets per channel per slot of the sample CD network is attainable at 13.65 packets per slot offered traffic. In contrast, the S-ALOHA network achieves the maximum throughput of 0.37 at 1 packet per channel per slot offered traffic. However, the 13.65 times increase in the offered traffic is in the expense of the 31 times increase in the network bandwidth. If we can utilize the same increase of bandwidth for the S-ALOHA system, the effective traffic that can be supported is 31 packets per slot. The efficiency of the sample CD network is therefore $\frac{13.65}{31} = 44\%$ of the S-ALOHA network.

It should be noted that the maximum throughput is not the only measure to conclude the effectiveness of a CD network. Other system parameters such as delay, stability, achievable throughput, complexity of the terminal design, bandwidth availability, and the incorporation of the random access technique into an operational protocol must also be considered. Furthermore, the analysis presented in this paper is based on a set of simplified assumptions and a sample CD network. The incorporation of the noise activity in the random access model may not reflect realistic conditions. Different conclusions may be drawn if the scenario changes. Detail studies must be conducted to determine the advantages and disadvantages of each channelization concept.

6 Summary

The throughput of CD under the random access scheme and the effects of voice activity factor have

m	$P_c(m)$	m	$P_c(m)$	m	$P_c(m)$
1	1.0	11	1.0	21	0.28
2	1.0	12	0.98	22	0.20
3	1.0	13	0.96	23	0.15
4	1.0	14	0.92	24	0.10
5	1.0	15	0.85	25	0.07
6	1.0	16	0.78	26	0.05
7	1.0	17	0.70		
8	1.0	18	0.60		
9	1.0	19	0.48		
10	1.0	20	0.37		

Table 5: Probability of Success for various m of Example 3

been investigated using a set of simplifying assumptions. It has been shown that the traditional rule of thumb of dividing the number of raw channels by the voice activity factor to obtain the effective number of channels is only valid asymptotically as the aggregated traffic approaches infinity under the demand-assigned approach for both CD and FD networks. The CD concept is compared with the traditional FD concept under the random access approach and a projected traffic model. It can be seen that CD is not particularly attractive for the first generation MSS with limited bandwidth. However, the CD concept is a viable alternative for future systems such as the personal access satellite system in the Ka-band spectrum with ample available bandwidth. It should be noted that there are many other factors affecting the choice of CD versus FD. A number of studies have been performed in search for a proper resource sharing scheme for PASS from different perspectives. Some of the comparisons can be found in [9, 10].

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References

[1] B. Levitt, et al., "A Unified Analysis of the Effects of Uplink Noise and Multi-User Interference on the End-to-End Performance of a DS/CDMA Bent -Pipe Satellite Relay System," JPL Internal report, December 19, 1989.

[2] K. Dessouky and M. Motamedi, "FDMA and CDMA PASS Design Tradeoffs, Comparisons of Results, and Conclusion," JPL IOM-3392-90-001, January 3, 1990. (Internal document)

[3] R. Pickholtz, D. Schilling, and L. Milstein, "Theory of Spread Spectrum Communications – A Tutorial," IEEE Trans. on Communications, COM-30, May, 1982. pp.855-884

[4] H. Xiang, "Binary Code-Division Multiple-Access Systems Operating in Multipath Fading, Noisy Channels," IEEE Trans. on Communications, COM-33, No. 8, August 1985. pp.775-784

[5] J. Hui, "Throughput Analysis for Code Division Multiple Accessing of the Spread Spectrum Channel," IEEE Journal on Selected Areas in Communications, SAC-2, July, 1984. pp.482-486

[6] J. Lehnert and M. Pursley, "Error Probabilities for Binary Direct-Sequence Spread-Spectrum Communications with Random Signature Sequences," IEEE Trans. on Communications, COM-35, No. 1, January 1987. pp.87-98

[7] R. Morrow and J. Lehnert, "Bit-to-Bit Error Dependence in Slotted DS/SSMA Packet Systems with Random Signature Sequences," IEEE Trans. on Communications, COM-37, No. 10, October 1989. pp.1052-1061

[8] D. Raychaudhuri, "Performance Analysis of Random Access Packet-Switched Code Division Multiple Access System," IEEE Trans. on Communications, COM-29, No. 6, June, 1981. pp.895-901

[9] M. Motamedi and M. Sue, "A CDMA Architecture for a Ka-Band Personal Access Satellite System: Complexity and Capacity," Proceeding 13th AIAA International Communication Satellite Systems Conference, Los Angeles, CA, March 11-15, 1990.

[10] K. Dessouky and M. Motamedi, "Multiple Access Capacity Trade-Offs for A Ka-Band Personal Access Satellite System," Proceeding International Mobile Satellite Conference, Ottawa, Ontario, Canada, June 18-20, 1990.