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AN ACCESS ALTERNATIVE FOR MOBILE SATELLITE NETWORKS

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ABSTRACT

Conceptually, this paper discusses strategies of digital satellite communication networks for a very large number of low density traffic stations. These stations can be either aeronautical, land mobile, or maritime. The techniques can be applied to international, domestic, regional, as well as special purpose satellite networks. The applications can be commercial, scientific, military, emergency, navigational or educational. The key strategy is the use of a non-orthogonal access method, which tolerates overlapping signals. With n being either time or frequency partitions, and with a single overlapping signal allowed, a low cost mobile satellite system can be designed with $n^2(n^2+n+1)$ number of terminals.

1. INTRODUCTION

As new demands and requirements of satellite communications change, the network strategy and the technological utilization need to change accordingly. Mobile satellite communication, either aeronautical, land or maritime, has created both technical and nontechnical challenges. Among the technical challenges likely to be encountered would be a network consisting of a very large number of small earth stations, where there is signal degradation due to deflection, reflection, shadowing, doppler shift, and other interference effects, as a consequence of receivers in motion and operation in various channel environments.

As an example of the number of stations in a mobile satellite network there are about 25,000 vessels above 1600 gross tonnage registered in the three oceanic regions, and there are around 330,000 general aviation aircrafts worldwide. By the year 2000 there are likely to be more than 12,000 commercial passenger-carrying airliners in operation [1]. For land mobile satellite communication, the number of users can be easily extended to six figures. On the other hand, because of the need for mobility, the size of user stations are getting smaller, which results in weaker signal reception and is increasingly prone to interference difficulties.

At present, all satellite networks, employing either mobile or fixed earth stations, operate on the principle of a controlling, or a number of controlling, stations. The network architecture is determined primary by the satellite access method used by the earth stations in the network. Since multiple access technique affects a satellite network more than any other network element, in this paper we therefore discuss multiple access strategies particularly from a mobile satellite network viewpoint. In Section 2, some background information on multiple access techniques is briefly described. In Section 3, the fundamental characteristics of random multiple access is outlined. In Section 4, the error probability expression is derived. The application of random multiple access to mobile satellite communication is discussed in the concluding remarks in Section 5.

2. BASIC ACCESS SCHEMES

Based on the resources of frequency, time, and space (or location), some of the basic access techniques for satellite communication are shown in Figure 1. From this it can be observed that most multiple access techniques can be derived from the division of combinations of the basic resources. Basic orthogonal access methods utilizing separate time and frequency division have been designed, implemented, and become operational on satellite networks. However, due to either frequency instability or time jittering, finer frequency or time division allocation alone becomes s practical difficulty for a network with a very large number of stations, and other access means must be sought.

As shown in Figure 1, when TDMA is combined with SDMA we have satellite-switched TDMA. When FDMA is combined with TDMA we have a time-frequency (TF) access scheme, which includes frequency hopping (FH) and time hopping (TH). When a spreading effect is applied to time we have time spreading (T-SPD); when it is applied to frequency we have frequency spreading (F-SPD) or a spread spectrum (SS) arrangement. From a mechanization standpoint, FH can produce F-SPD, as TH can produce T-SPD.

As indicated in Figure 1, we classify ALOHA multiple access systems as time division systems. ALOHA or ALOHA-derived systems are different from conventional TDMA systems in that ALOHA is not periodic in time and most message slots are not fixed in length. In ALOHA systems, although one can transmit messages randomly, the system cannot guarantee their reception randomly because of possible message collisions from other accessing stations. For this reason, we do not consider ALOHA-type access schemes to be truly random. The discussion of other access schemes such as satellite polling is omitted here and they can be found in [2]. In the next section, we discuss a different type of random multiple access, unrelated to ALOHA, for mobile satellite applications.

3. RANDOM MULTIPLE ACCESS

Starting with the use of the TF matrix for station access, depending on the division of time and frequency, with different detection and implementation process, variations of TF systems may be designed. Basically, a TF system makes use of the elements or cells of the time and frequency two-dimensional matrix resulting in the use of both time and frequency divisions. A specific type of access method, which utilizes the TF matrix and with deterministic signatures of prescribed characteristics, has been referred to as random multiple access (RMA). The definition, configuration, and the tradeoffs of such an access scheme are described in [2], and the signature generation algorithm for the purpose of random multiple accessing is illustrated in [3].

Depending on the practical constraints as to whether time or frequency can be more finely divided, n can be either the number of time or the number of frequency divisions. If n is the number of time divisions as shown in Figure 2, then it has been worked out by Wu [1], that:

The number of frequency divisions $f = n^2$
The number of symbols in the TF matrix $= n^3$
The number of stations in the network $= n^2(n^2+n+1)$.

In the derivation and proof of the above results, the assumptions were that n is a power of a prime (i.e., $n = p^m$), and single element overlap in the TF matrix is tolerated. In the case that time can be more finely divided as shown in Figure 3, then n becomes the number of frequency divisions, and n^2 the number of time divisions. The number of entries or symbols in the TF matrix and the number of earth stations in the network remain the same under the same condition of single element overlapping. The number of divisions n needed with respect to the number of stations in a network is shown in Table 1, with n up to 31 for near one million stations.

4. PERFORMANCE WITH ONBOARD QUEUE

In RMA, a collection of s signatures (addresses, or sequences) is assigned to each of the stations in the network. Each signature assembles E number of time-frequency elements out of a possible total number T x F, where T and F are the number of time and frequency division elements in a given frame. The receiver must determine which one of the s signatures was transmitted, based on the received E elements. Let us assume that the collection of E elements is randomly chosen, and the probability of the event for a particular E element to occur is $P(E) = E/TF$. The probability for this event not to occur is $P(\hat{E}) = 1 - P(E)$. For k users in the network not to have any one of the particular E elements, the probability is

$$P_k(\overline{E}) = [1 - P(E)]^k = \left[1 - \frac{E}{TF}\right]^k \qquad (1)$$

But for false detection to occur, all E elements must match, and this can occur with the probability

$$\begin{aligned} F_k(E) &= (1 - P_k(\overline{\mathrm{E}}))^E \\ &= \left\{1 - \left[1 - \frac{E}{TF}\right]^k\right\}^E \qquad (2) \end{aligned}$$

which can happen for any one of the E element collections. Since there are s number of collections (signatures), we then have for each user

$$F(k, E, s) = s\, F_k(E). \tag{3}$$

Now assume that a mobile satellite with an onboard queue, and a network in which all users are statistically independent, each user i with Poisson arrival rate λ_i and departure rate μ_i. If the users can only be increased or decreased one at a time (a realistic assumption), then the network can be modelled as a Markovian birth-death process. In this case, the probability of a station accessing in Δt is $\lambda_n \Delta t$, and that of a station dropping out is $\mu_n \Delta t$. The steady state probability of n accessing stations remaining in operation at time t is

$$P_n = P_o \prod_{i=1}^{n} \frac{\lambda_{i-1}}{\mu_i} \tag{4}$$

For a maximum number of K stations we have

$$\begin{aligned} \sum_{n=0}^{K} P_n &= P_o \sum_{n=0}^{K} \prod_{i=1}^{n} \frac{\lambda_{i-1}}{\mu_i} \\ &= P_o \left[1 + \sum_{n=1}^{K} \prod_{i=1}^{n} \frac{\lambda_{i-1}}{\mu_i} \right] = 1 \end{aligned} \tag{5}$$

or

$$P_o = \frac{1}{1 + \sum_{n=1}^{K} \prod_{i=1}^{n} \frac{\lambda_{i-1}}{\mu_i}} \tag{6}$$

The series in the denominator of (6) converges when $(\lambda_{i-1}/\mu_i) < 1$ for all i. Combining the results of (4), (6), (1), and (3), we have the false detection error probability,

$$F(k, E, s, K) = \sum_{k=0}^{K} P_k \cdot F(k,E,s)$$

$$= \frac{s\left\{1 - \left[1 - \frac{E}{TF}\right]^k\right\}^E \prod_{i=1}^{k} \frac{\lambda_{i-1}}{\mu_i}}{1 + \sum_{k=1}^{K} \prod_{i=1}^{k} \frac{\lambda_{i-1}}{\mu_i}} \tag{7}$$

where K is the maximum number of stations designed for the system, and k is the number of simultaneous stations accessing the satellite channel during the time of detection.

Equation (7) can be simplified for identical user parameters, i.e., $\lambda_i = \lambda$, $\mu_i = \mu$ for all i. A sample evaluation of (7) is shown in Table 2 which assumes $\lambda_{i-1} = \lambda$, $\mu_i = \mu$ for all i and K = 1,000; k varies from 10 to 60. For K equal to 60, E changes from 3 to 16, and ρ equal to 0.9, the false detection error probability F (k, E, s, K) is shown in Figure 4.

5. CONCLUDING REMARKS

Without referring to a specific application of aeronautical, land mobile, or maritime, this paper conceptually discusses the use of a random multiple access method with prescribed deterministic signatures for mobile satellite networks. In the special case of single element overlap being allowed, over a million station network can be designed for the signature length n = 32.

A possible RMA for mobile satellite network arrangement is shown in Figure 5, where RMA generation and detection functions may be combined into a coded phase modem. Such a modem is extensively discussed in the session on Modulation and Coding in this conference and elsewhere. On the other hand, for minimization of complexity or low cost reasons, digital frequency modulation or frequency shift keying scheme can also be used.

A new investigation on RMA is presently under way jointly by the University of Technology, Sydney and the Overseas Telecommunications Commission of Australia [4, 5].

REFERENCES

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[2] W.W. Wu, Elements of Digital Satellite Communication, Volume I - System Alternatives, Analyses and Optimization, Computer Science Press, 1984, Chapter 3.

[3] W.W. Wu, Elements of Digital Satellite Communication, Volume II - Channel Coding and Integrated Service Digital Satellite Networks, Computer Science Press, 1985, Chapter 3.

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Table 1

Parameters for RMA sequences up to length 31.

n	p^m	Number of Symbols n^3	Number of Stations $n^2(n^2+n+1)$
1	1^1	1	3
2	2^1	8	28
3	3^1	27	117
4	2^2	64	336
5	5^1	125	775
7	7^1	343	2793
8	2^3	512	4672
9	3^2	729	7371
11	11^1	1331	16093
13	13^1	2197	30927
16	2^4	4096	69888
17	17^1	4913	88723
19	19^1	6859	137541
23	23^1	12167	292537
27	3^3	19683	551853
29	29^1	24389	732511
31	31^1	29791	954273

Table 2

Calculations of false detection error probability in random multiple access.

E	ρ	K(Max. Stations) = 1000 k	$\bar{F}(k, E, s, K)$
3	.1	10	1.60333491E−05
4	.1	10	5.12182990E−07
8	.1	10	1.65816949E−15
16	.1	10	2.05177104E−38
3	.2	10	1.60493668E−05
4	.2	10	5.12694672E−07
8	.2	10	1.65982604E−15
16	.2	10	2.05382081E−38
3	.5	10	1.60493878E−05
4	.5	10	5.12695343E−07
8	.5	10	1.65982821E−15
16	.5	10	2.05382349E−38
3	1.0	10	1.60493811E−05
4	1.0	10	5.12695129E−07
8	1.0	10	1.65982752E−15
16	1.0	10	2.05382264E−38
3	.1	40	4.00833630E−06
4	.1	40	1.28045777E−07
8	.1	40	4.14542372E−16
16	.1	40	5.12942975E−39
3	.2	40	4.01234463E−06
4	.2	40	1.28173822E−07
8	.2	40	4.14956914E−16
16	.2	40	5.13455918E−39
3	.5	40	4.01234312E−06
4	.5	40	1.28173774E−07
8	.5	40	4.14956757E−16
16	.5	40	5.13455724E−39
3	1.0	40	4.01234312E−06
4	1.0	40	1.28173774E−07
8	1.0	40	4.14956757E−16
16	1.0	40	5.13455724E−39
3	.1	60	2.67222463E−06
4	.1	60	8.53638462E−08
8	.1	60	2.76361563E−16
16	.1	60	3.41961936E−39
3	.2	60	2.67489686E−06
4	.2	60	8.54492100E−08
8	.2	60	2.76637925E−16
16	.2	60	3.42303898E−39
3	.5	60	2.67489688E−06
4	.5	60	8.54492107E−08

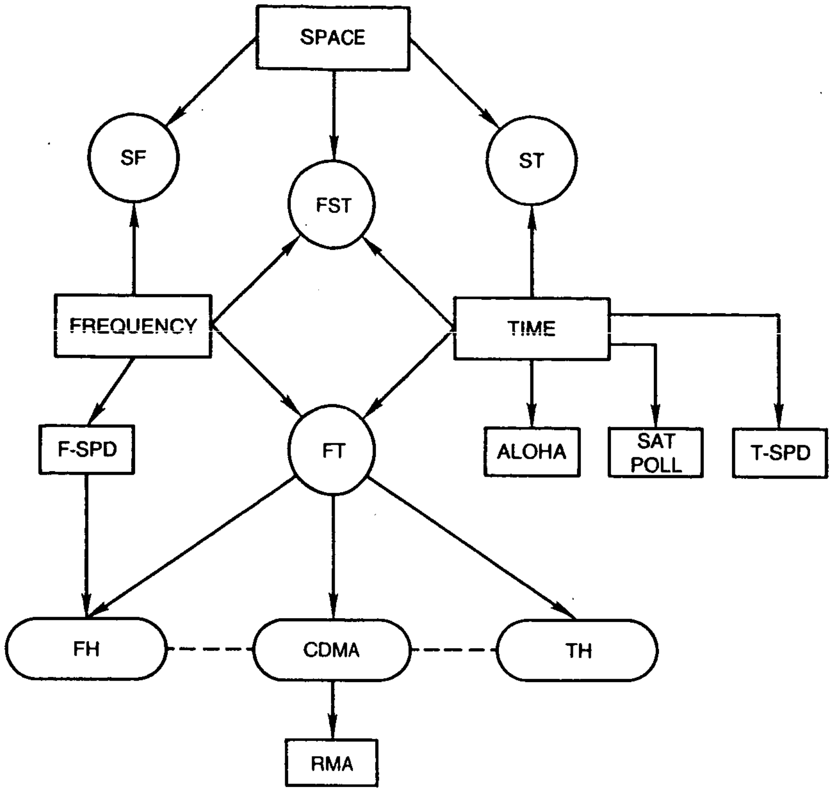

Figure 1
MULTIPLE ACCESS METHODS

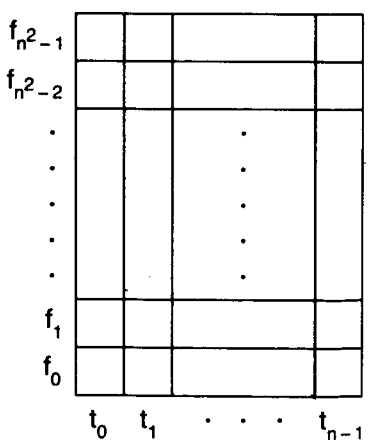

Figure 2
TF MATRIX WITH f = n^2

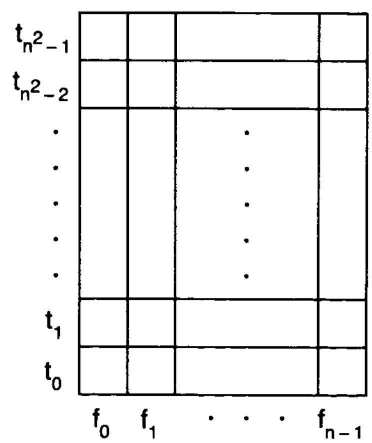

Figure 3
TF MATRIX WITH t = n^2

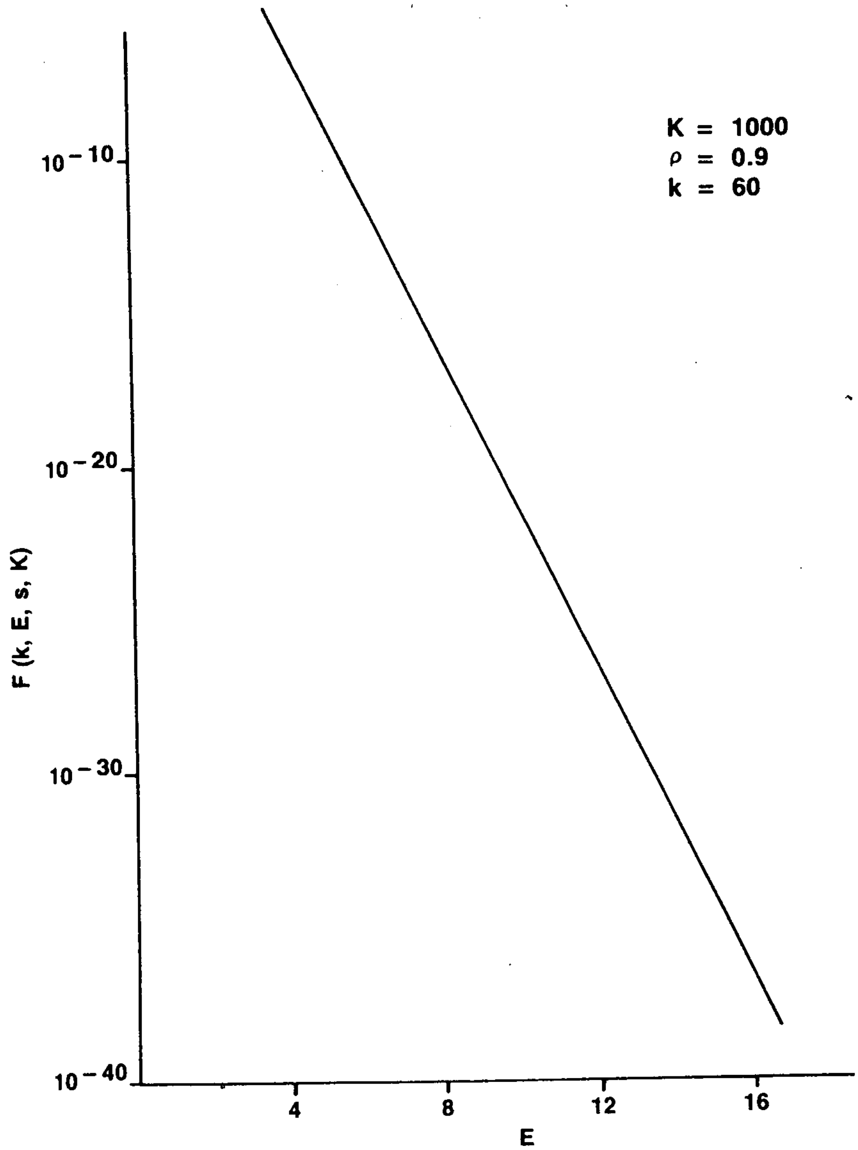

Figure 4
FALSE DETECTION ERROR PROBABILITY OF RANDOM MULTIPLE ACCESS SYSTEMS

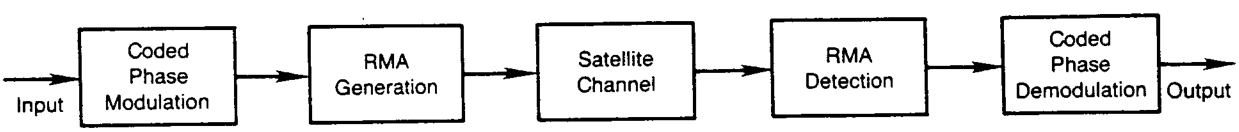

Figure 5
MOBILE SATELLITE APPLICATIONS WITH RANDOM MULTIPLE ACCESS