Improved Frame Synchronization Schemes for Inmarsat-B/M SCPC and TDM Channels

Si-Ming Pan, Randy L. Hanson, Donald H. Madill, and Paul C. Chapman
SED Systems Inc.
P.O. Box 1464
Saskatoon, Saskatchewan, Canada S7K 3P7
Phone: 306-931-3425
Fax: 306-933-1486

ABSTRACT

This paper proposes faster, more robust frame synchronization schemes for various Inmarsat-B and Inmarsat-M communication and signalling channels. Equations are developed which permit frame sync strategies of the type specified by Inmarsat to be evaluated in terms of average true lock time, average false maintenance time, and average search time. Evaluation of the currently specified framing schemes shows that a significant performance improvement is obtained by optimizing the threshold parameters of the scheme. The optimization seeks a compromise between the conflicting requirements of maximizing true lock time and minimizing search time.

INTRODUCTION

Frame synchronization is essential for time division multiplexed digital transmission. Inmarsat-B/M SCPC communication channels use framing to demultiplex the voice, sub-band data, and dummy bits; to synchronize the descrambler and FEC decoder; and to provide frame boundary indications for the voice decoder [1][2]. Inmarsat-B/M TDM signalling channels use framing for similar purposes. Frame synchronization statistics are also used as a real-time measure of in-service error performance on both types of channels.

The main motivation for considering frame synchronization performance improvement on these channels is related to its effect on overall synchronization performance. The overall synchronization scheme comprises in order carrier, clock, and frame synchronization parts. Each part is a necessary but not sufficient condition for subsequent parts. Therefore, overall sync acquisition performance depends on performance of each of its parts. If the frame synchronization part is implemented separately from the other parts, then overall acquisition performance remains constant as frame sync performance is improved, and combined carrier and clock acquisition performance is correspondingly relaxed. The overall acquisition performance requirements together with the specified frame synchronization scheme for these Inmarsat-B/M channels imply performance requirements on combined carrier and clock acquisition which are difficult to achieve especially under high bit error rate channel conditions. Therefore, improved frame sync schemes could make it easier to achieve cost-effective implementation of an overall synchronization scheme for these channels. In addition, a better framing scheme may result in more accurate and more reliable in-service error monitoring.

The performance of a framing scheme is typically described by three random quantities. These are a) the true lock time, T_{LO}, which is the time between true declaration of sync and false declaration of sync loss due to channel errors; b) the false maintenance time, T_{MF}, which is the time during which a false framing codeword pattern is temporarily assumed to be correct; and c) the search time, T_{FT}, which is the time required to locate the true framing codeword.

The true lock time (T_{LO}) gives a measure of the robustness of the framing scheme to channel bit errors. Because of random or burst channel errors, framing schemes may incorrectly determine that synchronization has been lost and initiate a new search for syncwords. When this false out-of-sync declaration occurs, the information in the frame is lost until synchronization is reacquired. In order to increase the information throughput and the reliability of in-service channel BER monitoring, a longer true lock time is desirable.

The false maintenance time (T_{MF}) gives a measure of the detectability of the scheme. Frame synchronization may actually be lost due to a large slip, lightning, or microwave switching. When these true out-of-sync events occur, the framing scheme should detect the event and then start a new search as soon as possible. This detection will take a variable amount of time, since information bit patterns may occasionally resemble the syncword pattern. A shorter false maintenance time is desirable.

The search time (T_{FT}) gives a measure of the speed of framing acquisition and reacquisition. A shorter search time is desirable.

The false maintenance time is in general a component of search time because incorrect acceptance of information bits as a frame boundary and then detection of the false acceptance can occur within the search process.

Other framing performance measures may be defined, but these are not directly relevant to the performance optimization with respect to threshold parameters discussed here. Optimization with respect to the number of consecutive syncword tests used to make search and lock decisions would involve other performance measures, such as the frequency of false detection, which is defined to be the probability of declaring an information bit pattern to be a syncword.

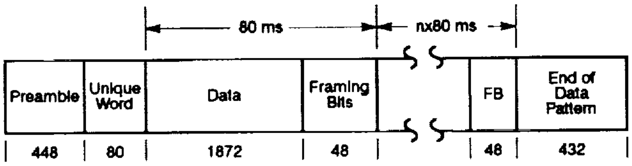
FRAME FORMATS AND FRAMING SCHEMES OF INMARSAT-B/M SCPC AND TDM CHANNELS

The frame format of the Inmarsat-B 24 kbps SCPC channel [1] is shown in Figure 1 (a), where the number of framing bits or syncword length is N=48 bits and the syncword repeats every frame length M=1920 bits, which corresponds to a frame duration T_M=80 ms. To obtain fast reacquisition for short interruptions by blocking and shadowing, the Inmarsat-M 8 kbps SCPC channel uses the N=24 bit unique word as the syncword in each M=480 bit subframe which corresponds to a subframe duration T_M=60 ms [2], as shown by Figure 1 (b). Figure 1 (c) illustrates the frame format of the Inmarsat-B/M 6 kbps TDM channel [1][2], where N=32 bits, M=1584 bits, and T_M=264 ms.

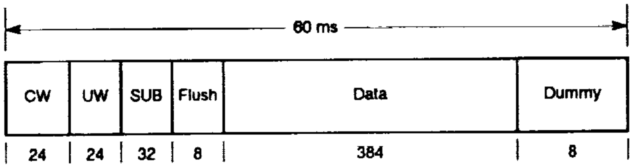
Frame sync strategies have been specified by Inmarsat for each of SCPC/B, SCPC/M, and TDM/B-M types of channels [1][2]. The framing scheme employed by Inmarsat for the 24 kbps SCPC/B channel is as follows:

(a) Frame synchronization loss shall be deemed to have occurred if "total frame pattern loss" has occurred in both of any two consecutive (exactly 80 ms apart) received framing bit patterns.

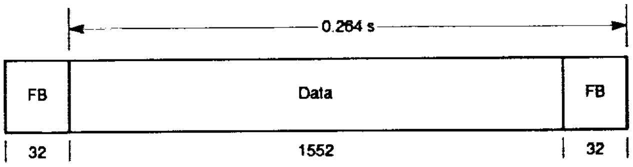
(b) Frame synchronization acquisition (or reacquisition) shall be deemed to have been achieved when two consecutive (exactly 80 ms apart) framing bit patterns are received without the occurrence of "partial frame pattern loss" in the first of the framing bit patterns and without the occurrence of "total frame pattern loss" in the second of the framing bit patterns.



(a) 24 kbps Inmarsat-B SCPC Communications Channel



(b) 8 kbps Inmarsat-M SCPC Communications Channel



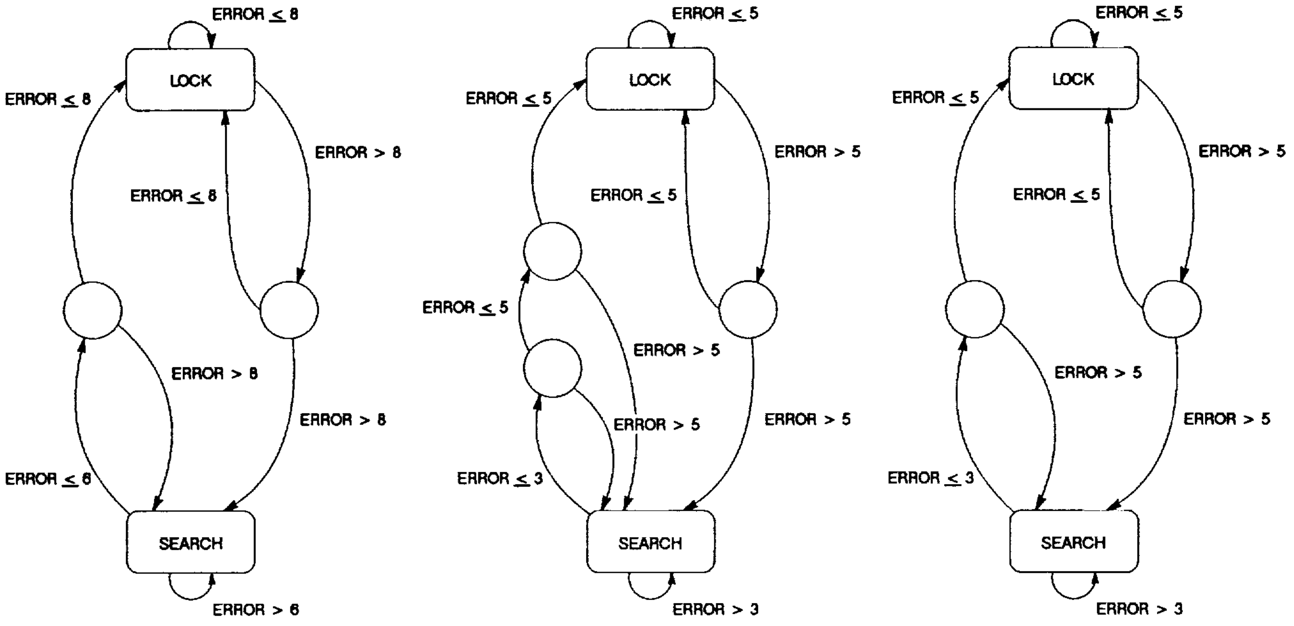
(c) 6 kbps Inmarsat-B/M TDM Signalling Channels

Figure 1. Frame Formats of Inmarsat SCPC and TDM Channels.

"Total frame pattern loss" and "partial frame pattern loss" are defined as the occurrence of more than 8 and 6 bit errors respectively in the 48 bit syncword.

If the error thresholds for "total frame pattern loss" and "partial frame pattern loss" are represented by e_m and e_s respectively, then setting e_m=8 and e_s=6 describes the SCPC/B framing scheme. Letting the number of consecutive pattern tests for frame sync acquisition and loss declaration be represented by α and β respectively, and then setting α=2 and β=2 further describes the Inmarsat-B SCPC channel framing scheme. Parameters e_m, e_s, α, and β are used to describe each framing scheme in this paper. The Inmarsat-specified values of these parameters for each framing scheme are given in Table 1.

The state transition diagram is commonly used to model a framing scheme [3][4]. For the framing scheme defined for the 24 kbps SCPC/B channel, the state transition diagram is given by Figure 2 (a). The framing scheme defined for the 8 kbps



(a) SCPC/B (b) SCPC/M (c) TDM/B-M

Figure 2. State Transition Models for Inmarsat-Specified Framing Schemes.

SCPC/M and 6 kbps TDM/B-M channel [1][2] is similarly obtained as shown by Figure 2 (b) and Figure 2 (c) respectively.

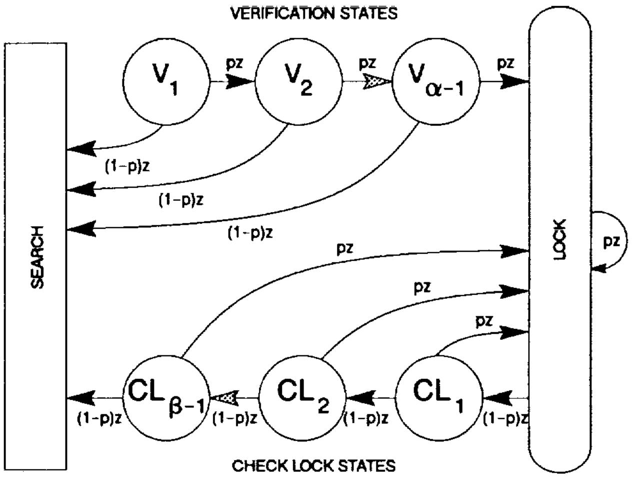
MEAN VALUES OF FRAMING PERFORMANCE MEASURES

The three performance measures—T_{LO}, T_{MF}, and T_{FT}—are random variables. Their expected values are used as the evaluation criteria upon which to determine an optimum scheme. Variance of these performance measures is not considered in the optimization. The probability distribution of these performance measures can be computed by using methods developed in [5].

To develop the mean of the true lock time ($\overline{T}_{LO}$)and the false maintenance time ($\overline{T}_{MF}$)for each of the three framing schemes, a general maintenance flow graph shown in Figure 3 is used. A substitute symbol p is used to represent transition probability P_{MF} for false maintenance and P_{MT} for true lock, where for given values of threshold e_m and channel error rate P_e:

$$P_{MF} = \sum_{x=0}^{e_m} \binom{N}{x} (0.5)^N \tag{1}$$

$$P_{MT} = \sum_{x=0}^{e_m} \binom{N}{x} P_e^{x} (1 - P_e)^{N-x} \tag{2}$$



p=P_{MF} for developing mean of T_{MF}
p=P_{MT} for developing mean of T_{LO}

Figure 3. General Maintenance Flow Graph for Framing Schemes.

The transition delays, z, in the flow graph are equal to T_M, whose value depends on the frame format under study. In the general flow graph, $(\alpha-1)$ consecutive verifications lead to declaration of correct alignment, indicated by V_1, V_2,... $V_{(\alpha-1)}$. Similarly, $(\beta-1)$ consecutive failed checks in the lock state are indicated by intermediate states CL_1, CL_2,...$CL_{(\beta-1)}$.

If V1 is defined as the starting state and the search state is defined as the absorbing state in the general flow graph, then the mean of the false maintenance time is obtained by evaluating the first derivative of the generating function for the resulting specific flow graph at z=1. The generating function is developed by applying Mason's formula on the flow graph [3]. The mean of the false maintenance time is determined to be

$$\bar{T}_{MF} = \left[\frac{1-(P_{MF})^{\alpha-2}}{(1-P_{MF})} + \frac{(P_{MF})^{\alpha-2}}{(1-P_{MF})^{\beta}} \right] T_M \qquad (3)$$

By using a similar analysis, but defining the lock state as the starting state, the mean of the true lock time is developed as

$$T_{LO} = \left[\frac{1 - (1-P_{MT})^{\beta}}{P_{MT}(1-P_{MT})^{\beta}} \right] T_M \qquad (4)$$

The search process is very complex. The mean and probability distribution of the search time has been developed [5], and the results are used in this paper. Assuming the starting position of the search process is uniformly distributed among all bit positions in a frame, the average search time may be computed from the average maximum reframe time ($\bar{T}_{RF}$) and the bit time (T_b) as

$$T_{FT} = \frac{1}{2} \left[\bar{T}_{RF} + (1-P_{AT}) \ \bar{T}_{RF} + T_b \right] \qquad (5)$$

The average maximum reframe time, which represents the worst case of the search starting position, is given [5] by

$$\bar{T}_{RF} = \frac{T_M + (M-1) P_{AF} \bar{T}_{MF}}{P_{AT}} \qquad (6)$$

where P_{AT} and P_{AF} are the transition probabilities for acquisition.

Assuming random information bits and sync-word patterns with sharply peaked autocorrelation, the transition probability P_{AF} and P_{AT} in (6) can be calculated by using

$$P_{AF} = \sum_{x=0}^{e_s} \binom{N}{x} (0.5)^N \qquad (7)$$

$$P_{AT} = \sum_{x=0}^{e_s} \binom{N}{x} P_e^{x} (1-P_e)^{N-x} \qquad (8)$$

PERFORMANCE EVALUATION AND OPTIMIZATION

Based on equations (1) through (8), the mean values of three performance measures (T_{LO}, T_{MF}, and T_{FT}) for each of the previously defined Inmarsat framing schemes are evaluated at various channel error rates. The channel error rate P_e ranges between 0.01 and 0.04 for Inmarsat SCPC and TDM channels at specified values of C/No. The evaluation is carried out for an extended channel error rate range from 0.1 to 0.01 in order to take the effect of deep fading into account.

The shortest possible search time, the shortest possible false maintenance time, and the longest possible true lock time are desired for any framing system. To find an optimum framing scheme, these performance measures should be calculated for a range of scheme parameters (e_m, e_s, α, and β).

It has been found that better performance may be obtained by using schemes with threshold parameters (e_m, e_s) different from those specified by Inmarsat. Framing schemes with significantly improved performance relative to the specified schemes have been found for each of the 24 kbps SCPC/B, 8 kbps SCPC/M, and 6 kbps TDM types of channels. The parameters of these improved framing schemes are given in Table 1. The evaluated performance of these improved schemes is given in Tables 2, 3, and 4. The performance of the framing schemes currently specified by Inmarsat is shown for comparison.

As indicated in Tables 2, 3, and 4, the suggested framing schemes show improved framing performance for all three types of channels. Compared with the specified schemes, the average true lock times of the suggested schemes are much longer, while the average search times and reframe times are either somewhat shorter or remain the same. False maintenance times are essentially the same for both specified and suggested schemes.

For a channel with errors, the designer must seek a compromise between the conflicting objectives of maximizing true lock time and minimizing false maintenance time. The improvement obtained in the true lock time results from the fact that appropriately increasing e_m greatly increases the true lock time while the false maintenance time is only slightly increased. This does not significantly alter the search performance. The improvement in search performance is obtained by finding a best combination of the values of e_s and e_m.

The framing performance may be further improved by changing the values of α and β. This

Table 1 Framing Scheme Parameters

		e_m	e_s	α	β
24 kbps SCPC/B	specified	(8)	(6)	(2)	(2)
	suggested	12	7	2	2
8 kbps SCPC/M	specified	(5)	(3)	(3)	(2)
	suggested	6	2	3	2
6 kbps TDM/B-M	specified	(5)	(3)	(2)	(2)
	suggested	7	3	2	2

Table 2 Performance Comparison between Specified and Suggested Framing Schemes for 24 kbps SCPC/B (T_M=80 ms)

		$\overline{T}_{LO}$ (hr)	$\overline{T}_{FT}$ (ms)	$\overline{T}_{RF}$ (ms)	$\overline{T}_{MF}$ (ms)
Specified Scheme	Pe=0.01	$1.6*10^{16}$	40.03	80.05	80.001
(e_m=8, e_s=6, α=2, β=2)	Pe=0.05	1816.2	40.24	80.24	80.001
	Pe=0.1	0.0664	49.14	89.15	80.001
Suggested Scheme	Pe=0.01	$2.5*10^{17}$	40.03	80.05	80.17
(e_m=12, e_s=7, α=2, β=2)	Pe=0.05	$7.83*10^{9}$	40.17	80.28	80.17
	Pe=0.1	704.3	44.02	80.30	80.17

Table 3 Performance Comparison between Specified and Suggested Framing Schemes for 8 kbps SCPC/M (T_M=60 ms)

		$\overline{T}_{LO}$ (hr)	$\overline{T}_{FT}$ (ms)	$\overline{T}_{RF}$ (ms)	$\overline{T}_{MF}$ (ms)
Specified Scheme	Pe=0.01	$1.8*10^{12}$	40.10	82.19	60.008
(e_m=5, e_s=3, α=3, β=2)	Pe=0.05	1033.7	42.09	82.68	60.008
	Pe=0.1	0.302	48.74	89.83	60.008
Suggested Scheme	Pe=0.01	$4.2*10^{15}$	32.00	63.99	60.065
(e_m=6, e_s=2, α=3, β=2)	Pe=0.05	85924.9	33.96	65.95	60.065
	Pe=0.1	5.886	49.44	81.44	60.065

Table 4 Performance Comparison between Specified and Suggested Framing Schemes for 6 kbps TDM/B/M (T_M=264 ms)

		$\overline{T}_{LO}$ (hr)	$\overline{T}_{FT}$ (ms)	$\overline{T}_{RF}$ (ms)	$\overline{T}_{MF}$ (ms)
Specified Scheme	Pe=0.01	$1.03*10^{11}$	134.02	268.04	264.14
(e_m=5, e_s=3, α=2, β=2)	Pe=0.05	97.31	139.584	273.60	264.14
	Pe=0.1	0.0591	205.91	339.93	264.14
Suggested Scheme	Pe=0.01	$6.1*10^{14}$	134.04	268.07	265.86
(e_m=7, e_s=3, α=2, β=2)	Pe=0.05	201088.0	139.590	273.63	265.86
	Pe=0.1	6.775	205.93	339.96	265.86

has not been done in this work. Changing the values of α and β will not only greatly affect the variance of the three performance measures, but also change the frequency of false detection. Frequency of false detection is nearly the same for Inmarsat-specified schemes as for the suggested improved schemes.

CONCLUSION

This paper has presented equations for performance measures that can be used to evaluate the framing performance of Inmarsat-B/M SCPC and TDM channels. Based on these equations, currently specified framing schemes have been evaluated and improved schemes have been proposed. These proposed schemes all show much longer average true lock times, very slightly longer average false maintenance times, and either nearly unchanged or shorter average search times. Thus, the proposed framing schemes would greatly improve the robustness of frame synchronization on these Inmarsat channels, especially for the case of high channel error rates. The significant reduction in false out-of-sync events not only increases information throughput but also reduces the frequency of false loss-of-synchronization alarms and therefore increases the reliability of real-time in-service channel BER monitoring. The proposed framing schemes also improve or leave unaffected the acquisition/reacquisition performance. Improved frame sync acquisition performance could ease implementation of the overall synchronization scheme. The only price paid for these improvements is a very slight degradation in the detectability performance of the schemes. The impact of this small degradation is not significant. These frame sync performance improvements can be achieved simply by changing the values of the threshold parameters of the framing scheme. This change is easy to perform on existing frame sync implementations. Therefore, it is recommended that these proposed schemes replace those currently specified by Inmarsat.

REFERENCES

[1] *Inmarsat-B System Definition Manual,* Issue 3.0, November 1991.

[2] *Inmarsat-M System Definition Manual,* Issue 3.0, November 1991.

[3] R. W. Sittler, "System Analysis of Discrete Markov Process," *IRE Transactions on Circuit Theory,* vol. CT-3, no. 12, pp. 257-66, 1956.

[4] E. V. Jones and M. N. Al-Subagh, "Algorithm for Frame Alignment - Some Comparisons," *IEE Proceedings,* vol. 132, no. 7, pp. 525-36, 1985.

[5] D. E. Dodds, S. M. Pan, and A. G. Wacker, "Statistical Distribution of PCM Framing Times," *IEEE Transactions on Communications,* vol. COM-36, no. 11, pp. 1270-75, 1988.