found to offer higher operating frequencies up to 3·2 GHz at a suitable supply voltage of 2·0 V consuming 24 mW. A supply voltage of only 1·2 V is sufficient to operate at 2·0 GHz dissipating only 4·6 mW with a 1 pF capacitive load. The process and design technology demonstrated here will enable a significant reduction of power dissipation, cost, and development time for a high-speed system, such as a multigigabit per second communication system.

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SOME CONTINUOUS MULTIDESTINATION ARQ SCHEMES FOR HIGH ERROR RATE CONDITIONS

Indexing terms: Telecommunications, Data transmission, Errors

A class of relatively simple continuous ARQ schemes with repeated transmissions suitable for multidestination communications under high error rate conditions is studied. In real applications, one can optimise the throughput performance by choosing the best scheme along those investigated with respect to the round-trip delay, the number of receivers and the block error probability. Results show that the optimal scheme may offer a far better performance than Morris's scheme for multidestination environments.

Introduction: The increasing applications of point-to-multipoint communication over a broadcast link such as teleconferencing and file distribution has prompted new efforts in the research of multidestination automatic repeat request (MARQ) techniques.[1–3] The three most popular ARQ schemes in use for point-to-point communications, namely the stop-and-wait (SW), the go-back-N (GBN) and the selective-repeat (SR) schemes, have been recently evaluated for multidestination environments. The multidestination SR (MSR) ARQ scheme clearly offers the best throughput performance.[7] The complexity of buffering for resequencing makes it impractical for real applications. The multidestination SW (MSW) and the multidestination GBN (MGBN) schemes are inefficient for high error rate conditions, especially when the round-trip delay and the number of receivers are large.

Three variant MARQ schemes for high error rate channels were evaluated in Reference 7. The three schemes can be considered as extended versions of Moeneclaey and Bruneel's,[4] Sastry's[5] and Morris's[6] schemes for multidestination environments. It was found that Morris' scheme has the best throughput performance among the three. Moeneclaey and Bruneel's scheme is the simplest to implement and offers almost the same throughput performance as Morris's scheme does under very high error rate conditions. In the letter we extend the results to a class of continuous MARQ schemes.

Investigated ARQ schemes: The operation of the investigated continuous ARQ schemes can be described as follows. A chunk of m ($m \geq 1$) or fewer copies of each data block are transmitted contiguously to the receivers. At each receiver, an error detection procedure is performed on each received copy. A positive acknowledgment (ACK) or a negative acknowledgment (NAK) is sent back to the transmitter according to whether the copy is received successfully or erroneously. The data block is considered to be successfully delivered as long as each receiver receives successfully at least one of the transmitted copies. If at least one receiver receives all the m copies with error, then, just as in the go-back-N ARQ scheme, the transmitter goes back to that data block. The same data block is retransmitted continuously until at least an ACK from each of the receivers which requested the transmitter to retransmit is received.

Consider the transmission of a particular data block. Assume that the round-trip delay between the transmitter and any receiver is the same, i.e., N blocks. As a result, if $m \leq N$, then all the m copies have to be transmitted before any response of the data block arrives at the transmitter. If $m > N$, then the transmitter may receive an ACK for the data block from each receiver before all the m copies are transmitted. When this occurs, the transmitter will start transmitting the next data block rather than continuing transmitting the rest of the copies. Therefore, the phrase 'or fewer' was used in the description of the operation of the investigated ARQ schemes.

Throughput performance: The system in our study consists of one transmitter and K receivers. For simplicity, transmission errors between copies of data blocks occur independently at each receiver and the feedback channel is assumed to be error-free. Let P_s denote the probability that a copy of a data block is received successfully by one receiver.

Consider a particular value of m. Let $\eta(m)$ denote the throughput efficiency. Clearly, if $L(m)$ represents the average number of transmissions required to successfully deliver a data block, then we have $\eta(m) = 1/L(m)$. It is therefore sufficient to compute the value of $L(m)$. Three cases are considered separately.

Case 1. $m = \infty$: For this case, a data block is transmitted continuously until the transmitter learns that each of the receivers receives at least one copy successfully. This scheme was actually evaluated in Reference 7. The result is

$$L(m) = S(P_s, K) + N - 1 \tag{1}$$

where

$$S(P_s, K) = \sum_{i=1}^{K} \binom{K}{i} \frac{(-1)^{i+1}}{1 - (1 - P_s)^i} \tag{2}$$

represents the average number of copies transmitted until all K receivers receive at least one copy successfully.

Case 2. $1 \leq m \leq N$: For this case, all the m copies are transmitted before the transmitter receives any response. Therefore, $L(m)$ can be computed recursively by

$$L(m) = m + \sum_{i=0}^{K-1} \binom{K}{i} [1 - (1 - P_s)^m]^i \times [(1 - P_s)^m]^{K-i} [2(N - 1) + S(P_s, K - i)] \tag{3}$$

Case 3. $N < m < \infty$: When $m > N$, the transmitter may receive an ACK from each receiver before all the m copies are transmitted. Let $Q_j(K)$ denote the probability that all the K receivers successfully receive the data block in j copies

$$Q_j(K) = [1 - (1 - P_s)^j]^K \tag{4}$$

Let $R_j(K)$ denote the probability that the K receivers receive the data block successfully exactly at the jth copy

$$R_j(K) = Q_j(K) - Q_{j-1}(K) \tag{5}$$

Then $L(m)$ can be evaluated by

$$\begin{aligned} L(m) = {} & \sum_{j=1}^{m-N} R_j(K)(j + N - 1) + m \sum_{j=m-N+1}^{m} R_j(K) \\ & + \sum_{i=0}^{K-1} \binom{K}{i} [1 - (1 - P_s)^m]^i \\ & \times [(1 - P_s)^m]^{K-i} [m + 2(N - 1) + S(P_s, K - i)] \end{aligned} \tag{6}$$

Numerical results and discussions: Fig. 1 shows the throughput efficiencies of the MSR, MGBN, Morris's scheme, and the optimal scheme among the investigated ones against P_s for $N = 5$ and $K = 5$. The throughput efficiencies of the MSR, MGBN and Morris's schemes are equal to $1/S(P_s, K)$, $1/[1 - N + NS(P_s, K)]$ and $1/[(N - 1)(1 - P_s^K) + S(P_s, K)]$, respectively. One can see that the optimal scheme provides a significant improvement in throughput efficiency over Morris's scheme for $P_s \in [0.4, 0.9]$. The percentage of improvement is about 31% at $P_s = 0{\cdot}85$.

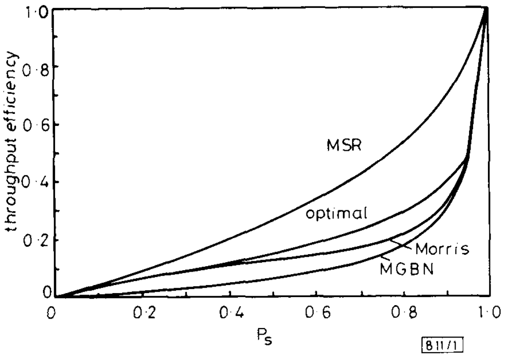

Fig. 1 *Throughput efficiency against P_s*
$N = 5; K = 5$

Figs. 2 and 3 shows similar results for $N = 10$, $K = 5$ and $N = 5$, $K = 20$, respectively. Comparing Figs. 1, 2 and 3. one can see that the improvement is more significant when N and/or K are larger. In reality, the improvement at $P_s = 0.85$ is about 101% and 74% for $N = 10$, $K = 5$ and $N = 5$, $K = 20$, respectively.

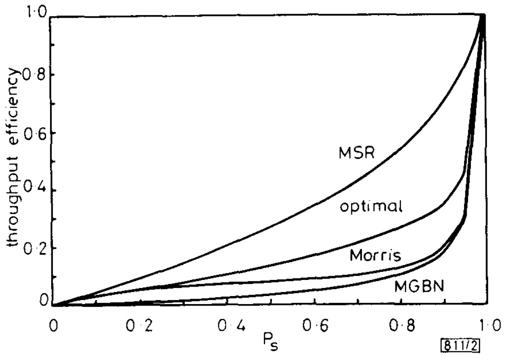

Fig. 2 *Throughput efficiency against P_s*
$N = 10; K = 5$

There are several interesting topics in this area that can be studied further. For example, it is worth evaluating the performance of various ARQ schemes for multidestination environments where round-trip delays between the transmitter and different receivers are not the same.

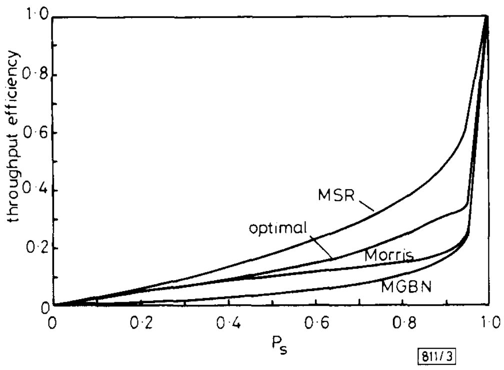

Fig. 3 *Throughput efficiency against P_s*
$N = 5; K = 20$

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TWO-BAND IIR QUADRATURE MIRROR FILTER DESIGN

Indexing term: Filters

Two types of two-band IIR quadrature mirror filter structure are proposed. The aliasing distortion and amplitude distortion can be exactly cancelled. The Remez exchange algorithm is used iteratively to optimise the filter response, which results in an equal-ripple design.

Introduction: Quadrature mirror filters (QMF) have great applications in sub-band coding systems.[1,2] In general, a sub-band coding system suffers from three kinds of distortions: aliasing distortion, amplitude distortion and phase distortion. If a sub-band coding system is free from these three distortions, it is called a 'perfect reconstruction' system. Theoretically, only FIR filter banks can achieve perfect reconstruction.[3] Ordinary FIR filters have large transition band. If both a sharp transition band and reasonable stopband attenuation are required, one must use very high order