Robust Coding Schemes for Distributed Sensor Networks with Unreliable Sensors

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Abstract — We consider a distributed sensor network in which several observations are communicated to the fusion center using limited transmission rate. The observations must be separately coded. We introduce a class of robust distributed coding schemes which flexibly trade off between system robustness and compression efficiency.

I. INTRODUCTION

Consider the distributed sensor network shown in Fig. 1. \( \{X(t)\}_{t=1}^{\infty} \) is the target data sequence which the fusion center tries to recover. This data sequence may not be observed directly. Corrupted versions of \( x_t \) may transmit information about its observations is limited to \( R_i \) bits per second. The sensors are not permitted to communicate with each other; i.e., Sensor \( i \) has to send data based solely on its own noisy observations \( \{X_i(t)\}_{t=1}^{\infty} \).

Figure 1: Model of distributed sensor network with unreliable sensors

Let \( \{X(t), Y_1(t), Y_2(t)\}_{t=1}^{\infty} \) be temporally memoryless source with instantaneous joint probability distribution \( P(x, y_1, y_2) \) on \( X \times Y_1 \times Y_2 \), where \( X \) is the common alphabet of the random variables \( X(t) \) for \( t = 1, 2, \ldots \); \( Y_i \) (\( i = 1, 2 \)) is the common alphabet of the random variables \( Y_i(t) \) for \( t = 1, 2, \ldots \). If Sensor \( i \) is enabled, then it encodes a block \( y_i^n = [y_i(1), \ldots, y_i(n)] \) of length \( n \) from its observed data using a source code \( c_i^{(n)} = f_i^{(n)}(y_i^n) \) of rate \( \frac{1}{n} \log |c_i^{(n)}| \). If the fusion center only receives the data from Sensor \( i \), it then tries to recover the target sequence \( x^n = [x(1), \ldots, x(n)] \) by implementing a mapping \( f_{D,i} : c_i \rightarrow x^n \) (\( i = 1, 2 \)). If the fusion center receives the data from both sensors, then it tries to recover the target sequence by implementing a mapping \( f_{D,3} : c_1^{(n)} \times c_2^{(n)} \rightarrow x^n \).

This model subsamples the multiple description problem [1] and the CEO problem [2], and was first studied in [3].

Definition 1 The quintuple \( (R_1, R_2, D_1, D_2, D_3) \) is called achievable, if \( \forall \varepsilon > 0, \exists n_0 \) such that \( \forall n > n_0 \) there exists encoding functions:

\[
f_{E,i}^{(n)} : y_i^{(n)} \rightarrow c_i^{(n)}, \quad \log |c_i^{(n)}| \leq n(R_i + \varepsilon) \quad i = 1, 2
\]

\[
f_{D,3} : c_1^{(n)} \times c_2^{(n)} \rightarrow x^n
\]

such that for \( \hat{x}_i^n = f_{D,i}(f_{E,i}(y_i^n)) \) (\( i = 1, 2 \)) and for

\[
\frac{1}{n} E \sum_{t=1}^{n} d(X(t), \hat{x}_i(t)) < D_i + \varepsilon \quad i = 1, 2, 3.
\]

Here \( d(\cdot, \cdot) : X \times X \rightarrow [0, d_{\text{max}}] \) is a given distortion measure. Let \( Q \) denote the set of all achievable quintuples.

II. MAIN RESULTS

Theorem 1 \( (R_1, R_2, D_1, D_2, D_3) \) is achievable, if there exist random variables \( (W_1, W_2, W_1, W_2, W_2) \) jointly distributed with the generic source variables \( (X, Y_1, Y_2) \) such that the following properties are satisfied:

(i) \( (W_1, W_1, W_2) \rightarrow Y_1 \rightarrow (X, Y_2, W_1, W_2) \),

\( (W_1, W_2, W_2) \rightarrow Y_2 \rightarrow (X, Y_1, W_1, W_2) \);

(ii) \( R_1 \geq I(Y_1; W_1, W_2) + I(Y_1; W_1, W_2, W_1, W_2) \),

\( R_2 \geq I(Y_2; W_2, W_2) + I(Y_2; W_2, W_2, W_1, W_2, W_2) \),

\( R_1 + R_2 \geq I(Y_1; W_1, W_2) + I(Y_2; W_2, W_2, W_1, W_2, W_2) \); or

(iii) There exist functions:

\( f_i : W_i \rightarrow X \quad i = 1, 2, \)

\( f_3 : W_1, W_2 \rightarrow W_2, W_2, W_2 \rightarrow \mathcal{X} \),

such that \( Ed(X, \hat{X}_i) \leq D_i \) (\( i = 1, 2, 3 \)), where \( \hat{X}_1 = f_1(W_1), \hat{X}_2 = f_2(W_2) \) and \( \hat{X}_3 = f_3(W_1, W_2, W_1, W_2, W_2) \).

If \( C \) denotes the set of these achievable quintuples, then time sharing yields that conv(\( C \)) is also an achievable region.

REFERENCES

