Synthesis of MPEG-like Standard with Interval Multiset Estimates

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***Abstract*—The paper addresses modular modeling, design, and improvement of MPEG-like standard for multimedia information processing. Morphological (modular) system design and improvement are considered as composition of the standard elements (components) configuration. The solving process is based on Hierarchical Morphological Multicriteria Design (HMMD) approach: (i) multicriteria selection of alternatives for system components, (ii) synthesis of the selected alternatives into a resultant combination. Assessment of design alternatives is based on interval multiset estimates, assessment of compatibility between the design alternatives is based on ordinal scale. Improvement of the obtained solutions is examined as well (knapsack-like problem). Numerical examples illustrate the design process.**

***Keywords*-standard for multimedia information; combinatorial synthesis; combinatorial optimization; multiset.**

I. INTRODUCTION

In recent decades, the significance of multimedia information processing is increased (e.g., [1], [2], [7], [8]). A structural approach to modeling of MPEG-like standard for multimedia information has been presented in [14]. Multicriteria analysis of algorithms for processing of image sequences to reveal Pareto-efficient methods for some typical image sequences was studied in [4]. This work is a basis for on-line selection of the best processing algorithms for an input image sequence. In [12], an example for combinatorial synthesis of MPEG-like standard was described. This paper focuses on combinatorial synthesis of MPEG-like standard and its improvement with using interval multiset estimates of standard elements. The approach can be considered as a basis for on-line design and modification of the standards in multimedia information processing.

Morphological (modular) system design and improvement are considered as composition of elements of MPEG-like standard (components, e.g., rules, algorithms). Hierarchical Morphological Multicriteria Design (HMMD) approach is used for modular design with interval multiset estimates for assessment of design alternatives (DAs) for elements of standard. This composition method (with interval multiset estimates) has been suggested in [10] and was used in some synthesis works (e.g., [11], [13]). HMMD implements a multi-stage design framework and provides cascade-like design framework:

(1) Decomposition/partitioning of system and system requirements to obtain a hierarchical system model and a hierarchy of system requirements, which correspond to system parts/components,

(2) 'Bottom-Up' design process:

(i) multicriteria selection of design alternatives (DAs) for system components,

(ii) synthesis of the selected alternatives into a resultant combination.

The additional systems problem is examined: improvement of the obtained solutions (multiple choice problem).

Fig. 1 depicts a simplified scheme of the approach.

The numerical design examples involve hierarchical system structure of MPEG-like standard, DAs for system parts/components, estimates of DAs and their compatibility, Bottom-Up design process, analysis and improvement of the obtained system solutions. Assessment of DAs and their compatibility is based on expert judgment.

The structure of the paper is the following. Section II presents description of combinatorial synthesis with interval multiset estimates. In Section III, hierarchical modeling of the MPEG-like standard (including design alternatives for leaf nodes of the model) and combinatorial synthesis of four Pareto-efficient solutions (on the basis of HMMD) are described. Section IV presents improvement of the obtained solutions as selection of improvement actions (on the basis of multiple choice problem).

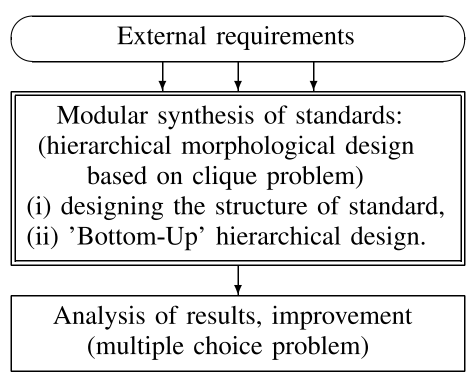

Figure 1. Simplified design framework

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II. SYNTHESIS WITH INTERVAL MULTISET ESTIMATES

This section presents a compressed description of combinatorial synthesis with interval multiset estimates, which has been suggested in [10]. Close compressed materials are contained in ([11], [12],[13]).

The approach consists in assignment of elements $(1, 2, 3, ...)$ into an ordinal scale $[1, 2, ..., l]$. As a result, a multi-set based estimate is obtained, where a basis set involves all levels of the ordinal scale: $\Omega = \{1, 2, ..., l\}$ (the levels are linear ordered: $1 \succ 2 \succ 3 \succ ...$) and the assessment problem (for each alternative) consists in selection of a multiset over set Ω while taking into account two conditions:

1. Cardinality of the selected multiset equals a specified number of elements $\eta = 1, 2, 3, ...$ (i.e., multisets of cardinality η are considered);

2. "Configuration" of the multiset is the following: the selected elements of Ω cover an interval over scale $[1, l]$ (i.e., "interval multiset estimate").

Thus, an estimate e for an alternative A is (scale $[1, l]$, position-based form or position form): $e(A) = (\eta_1, ..., \eta_\iota, ..., \eta_l)$, where η_ι corresponds to the number of elements at the level ι ($\iota = \overline{1, l}$), or $e(A) = \{\overbrace{1, ..., 1}^{\eta_1}, \overbrace{2, ...2}^{\eta_2}, \overbrace{3, ..., 3}^{\eta_3}, ..., \overbrace{l, ..., l}^{\eta_l}\}$. The number of multisets of cardinality η, with elements taken from a finite set of cardinality l, is called the "multiset coefficient" or "multiset number" ([6],[15]): $\mu^{l,\eta} = \frac{l(l+1)(l+2)...(l+\eta-1)}{\eta!}$. This number corresponds to possible estimates (without taking into account interval condition 2). In the case of condition 2, the number of estimates is decreased. Generally, assessment problems based on interval multiset estimates can be denoted as follows: $P^{l,\eta}$. The assessment problem $P^{3,4}$ will be used in numerical examples.

In addition, operations over multiset estimates are used [10]: integration, vector-like proximity, aggregation.

Integration of estimates (mainly, for composite systems) is based on summarization of the estimates by components (i.e., positions). Let us consider n estimates (position form): estimate $e^1 = (\eta^1_1, ..., \eta^1_\iota, ..., \eta^1_l)$, . . ., estimate $e^\kappa = (\eta^\kappa_1, ..., \eta^\kappa_\iota, ..., \eta^\kappa_l)$, . . ., estimate $e^n = (\eta^n_1, ..., \eta^n_\iota, ..., \eta^n_l)$. Then, the integrated estimate is: estimate $e^I = (\eta^I_1, ..., \eta^I_\iota, ..., \eta^I_l)$, where $\eta^I_\iota = \sum_{\kappa=1}^{n} \eta^\kappa_\iota \quad \forall \iota = \overline{1, l}$. In fact, the operation $\biguplus$ is used for multiset estimates: $e^I = e^1 \biguplus ... \biguplus e^\kappa \biguplus ... \biguplus e^n$.

Vector-like proximity is considered as follows. Let A_1 and A_2 be two alternatives with corresponding interval multiset estimates $e(A_1)$, $e(A_2)$. Vector-like proximity for the alternatives above is: $\delta(e(A_1), e(A_2)) = (\delta^-(A_1, A_2), \delta^+(A_1, A_2))$, where vector components are: (i) δ^- is the number of one-step changes: element of quality $\iota + 1$ into element of quality ι ($\iota = \overline{1, l-1}$) (this corresponds to "improvement"); (ii) δ^+ is the number of one-step changes: element of quality ι into element of quality $\iota + 1$ ($\iota = \overline{1, l-1}$) (this corresponds to "degradation"). It is assumed: $|\delta(e(A_1), e(A_2))| = |\delta^-(A_1, A_2)| + |\delta^+(A_1, A_2)|$.

A median (aggregated) estimate (aggregation) for a set of initial estimates is defined as follows. Let $E = \{e_1, ..., e_\kappa, ..., e_n\}$ be the set of initial estimates. let D be the set of all possible estimates ($E \subseteq D$). Thus, the median estimates ("generalized median" M^g and "set median" M^s) are: $M^g = \arg\min_{M \in D} \sum_{\kappa=1}^{n} |\delta(M, e_\kappa)|$; $M^s = \arg\min_{M \in E} \sum_{\kappa=1}^{n} |\delta(M, e_\kappa)|$.

A brief description of combinatorial synthesis (HMMD) with ordinal estimates of design alternatives is the following ([9], [10]). An examined composite (modular, decomposable) system consists of components and their interconnection or compatibility (IC). Basic assumptions of HMMD are the following: *(a)* a tree-like structure of the system; *(b)* a composite estimate for system quality that integrates components (subsystems, parts) qualities and qualities of IC (compatibility) across subsystems; *(c)* monotonic criteria for the system and its components; *(d)* quality of system components and IC are evaluated on the basis of coordinated ordinal scales. The designations are: (1) design alternatives (DAs) for leaf nodes of the model; (2) priorities of DAs ($\iota = \overline{1, l}$; 1 corresponds to the best one); (3) ordinal compatibility for each pair of DAs ($w = \overline{1, \nu}$; ν corresponds to the best one). Let S be a system consisting of m parts (components): $R(1), ..., R(i), ..., R(m)$. A set of design alternatives is generated for each system part above. The problem is:

Find a composite design alternative $S = S(1) \star ... \star S(i) \star ... \star S(m)$ *of DAs (one representative design alternative* $S(i)$ *for each system component/part* $R(i)$, $i = \overline{1, m}$ *) with non-zero compatibility between design alternatives.*

A discrete "space" of the system excellence (a poset) on the basis of the following vector is used: $N(S) = (w(S); e(S))$, where $w(S)$ is the minimum of pairwise compatibility between DAs, which correspond to different system components (i.e., $\forall\ R_{j_1}$ and R_{j_2}, $1 \le j_1 \ne j_2 \le m$) in S, $e(S) = (\eta_1, ..., \eta_\iota, ..., \eta_l)$, where η_ι is the number of DAs of the ιth quality in S. Further, the problem is described as follows:

$$\max\ e(S), \quad \max\ w(S), \quad s.t.\ \ w(S) \ge 1. \qquad (1)$$

As a result, we search for composite solutions, which are nondominated by $N(S)$ (i.e., Pareto-efficient). "Maximization" of $e(S)$ is based on the corresponding poset. The considered combinatorial problem is NP-hard and enumerative solving schemes or heuristics are used.

In the article, combinatorial synthesis is based on usage of multiset estimates of design alternatives for system parts. For the resultant system $S = S(1) \star ... \star S(i) \star ... \star S(m)$ the same type of the multiset estimate is examined: an aggregated estimate ("generalized median") of corresponding multiset estimates of its components (i.e., selected DAs). Thus,

$N(S)=(w(S);e(S))$, where $e(S)$ is the "generalized median" of estimates of the solution components. The modified problem is:

$$\max\ e(S)=M^g=\arg\min_{M\in D}\ \sum_{i=1}^{m}\ |\delta(M,e(S_i))|,$$
$$\max\ w(S),$$
$$s.t.\qquad w(S)\geq 1. \qquad (2)$$

Here, enumeration methods or heuristics are used ([9], [10]).

The basic multiple choice problem is (e.g., [3], [5]):

$$\max\sum_{i=1}^{m}\sum_{j=1}^{q_i}c_{ij}x_{ij}$$
$$s.t.\ \sum_{i=1}^{m}\sum_{j=1}^{q_i}a_{ij}x_{ij}\leq b;\ \sum_{j=1}^{q_i}x_{ij}\leq 1,\ i=\overline{1,m};$$
$$x_{ij}\in\{0,1\}. \qquad (3)$$

In the case of multiset estimates of item "utility" $e_i, i\in\{1,...,i,...,m\}$ (instead of c_i), an aggregated multiset estimate as the "generalized median" is used. The item set is: $A=\bigcup_{i=1}^{m}A_i,\ \ A_i=\{(i,1),(i,2),...,(i,q_i)\}$. Boolean variable $x_{i,j}$ corresponds to selection of the item (i,j). The solution is a subset of the initial item set: $S=\{(i,j)|x_{i,j}=1\}$. The problem is:

$$\max\ e(S)=\max\ M=$$
$$\arg\min_{M\in D}\ \sum_{(i,j)\in S=\{(i,j)|x_{i,j}=1\}}|\delta(M,e_{i,j})|,$$
$$s.t.\ \ \sum_{i=1}^{m}\sum_{j=1}^{q_i}a_{ij}x_{i,j}\leq b;\qquad \sum_{j=1}^{q_i}x_{ij}=1;$$
$$x_{ij}\in\{0,1\}. \qquad (4)$$

In the paper, a greedy heuristic is used.

III. Structure of Standard and Synthesis

Hierarchical modular structure of MPEG-like standard has been examined in [14]. A simplified hierarchical model of MPEG-like standard was analyzed in [14]. Here, a modification of the above-mentioned hierarchical model is considered (Fig. 2):

0. MPEG-like standard $S=A\star B$.

1. General part $A=C\star B\star D\star E\star F$:

1.1. Applied layer (videotelephony, videoconferencing, digital broadcast, digital storage media, etc.) C: bit rate 64 kbit/s ... 2 Mbit/s $C_1(1,3,0)$; bit rate 4...80 Mbit/s $C_2(2,2,0)$; bit rate 24...1024 Mbit/s, Web, security for applications $C_3(0,4,0)$.

1.2. Time and picture quality mode $D=X\star Y$: *1.2.1.* Time mode X: delay $X_1(0,2,2)$, real time, low delay $X_2(1,3,0)$; *1.2.2.* Picture quality Y: low $Y_1(0,3,1)$, good $Y_2(3,1,0)$, variable $Y_3(1,3,0)$.

1.3. Format $E=U\star V$: *1.3.1.* Resolution U: low $U_{1,2,1}(3)$, high $U_{0,2,2}$; *1.3.2.* Color decomposition V: basic $V_1(1,2,1)$, high profile $V_2(0,2,2)$.

1.4. Basic operations $F=T\star P\star M$: *1.4.1.* Transformation T: basic mode $T_1(1,3,0)$, Dolby Digital $T_2(1,2,1)$; *1.4.2.* Playback/features P: basic mode $P_1(1,3,0)$, with scalability $P_2(1,2,1)$; *1.4.3.* Streaming (video, audio, synchronization, streaming data, testing, control) M: basic mode $M_1(1,3,0)$, media objects $M_2(1,2,1)$, real-time streaming $M_3(0,3,1)$.

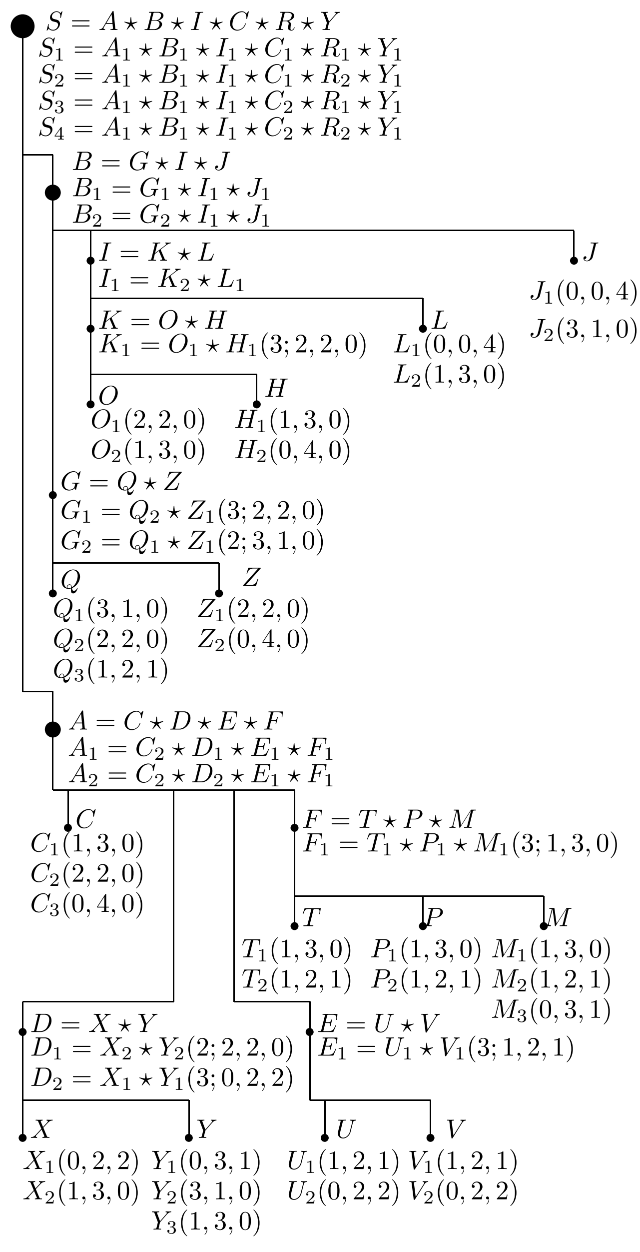

Figure 2. Considered structure of MPEG-like standard

2. Coding/compression $B = G \star I \star J$.

2.1. Basic components $G = Q \star W \star Z$: *2.1.1.* Video coding (methods for transformation into digital codes) Q: variable word length coding of coefficient structure $Q_1(1)$, VLC tables for DCT (non-linear) $Q_2(2)$, flexibility of coding for audio/videa $Q_3(2)$; *2.1.2.* Motion estimation (vector, etc.) Z: $-1024...1023$ pixel (for half) $Z_1(3)$, $-2048...2047$ pixel (for full) $Z_2(1)$.

2.2. Principles and structure $I = K \star L$:

2.2.1. Principles $K = O \star H$: *2.2.1.1.* Block decomposition O: 16 $times$16 (macroblock) and 8×8 (block) $O_1(2,2,0)$, object-based (VOB) $O_2(1,3,0)$; *2.2.1.2.* Scanning H: progressive scan (zigzag) $H_1(1,3,0)$, alternative $H_2(0,4,0)$.

2.2.2. Structure (basic processing scheme, extended processing scheme, 'open structure' including transcoding) L: basic mode $L_1(1)$, separation of motion and texture data $L_2(2)$.

2.3. Algorithms J: simple $J_1(2)$ complicated $J_2(1)$.

Interval multiset estimates of DAs are presented in Fig. 2 (in parentheses, expert judgment, illustrative character).

The following abbreviations are used hereinafter: Dolbi Digital (format Dolbi Digital), VLC (Variable-Length Coding), DCT (Discrete Cosine Transform),

Compatibility estimates are presented in Table 1 and Table 2 (expert judgment).

The obtained intermediate composite DAs for subsystems are the following: (1) $D_1 = X_2 \star Y_2$, $N(D_1) = (2;2,2,0)$; (2) $D_2 = X_1 \star Y_1$, $N(D_2) = (3;0,2,2)$; (3) $E_1 = U_1 \star V_1$, $N(E_1) = (3;1,2,1)$; (4) $F_1 = T_1 \star P_1 \star M_1$, $N(F_1) = (3;1,3,0)$; (5) $G_1 = Q_2 \star Z_1$, $N(G_1) = (3;2,2,0)$; (6) $G_2 = Q_1 \star Z_1$, $N(G_1) = (2;3,1,0)$; (7) $K_1 = O_1 \star H_1$, $N(K_1) = (3;2,2,0)$. Fig. 3 illustrates quality of intermediate composite DAs for subsystems D, F, G, K.

TABLE I. COMPATIBILITY ESTIMATES

	Y_1	Y_2	Y_3
X_1	3	2	2
X_2	2	2	2

	V_1	V_2
U_1	3	2
U_2	2	3

	P_1	P_2	M_1	M_2
T_1	3	2	3	1
T_2	1	3	1	3
P_1			3	2
P_2			2	3

TABLE II. COMPATIBILITY ESTIMATES

	Z_1	Z_2
Q_1	2	1
Q_2	3	2
Q_3	1	1

	H_1	H_2
O_1	3	2
O_2	2	3

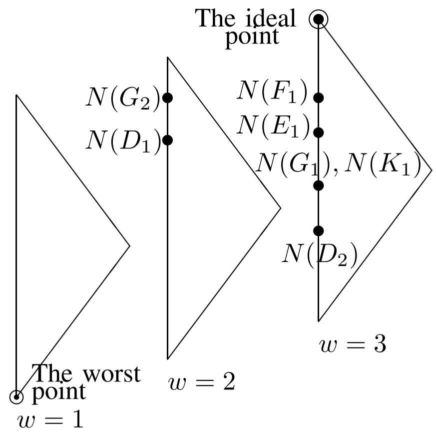

Figure 3. Quality for D,F,G,K

Further, combinations at the next higher level of the hierarchical system model are as follows:

(a) $A_1 = C_2 \star D_1 \star E_1 \star F_1$, (b) $A_2 = C_2 \star D_2 \star E_1 \star F_1$,

(c) $B_1 = G_1 \star I_1 \star J_1$, (d) $B_2 = G_2 \star I_1 \star J_1$.

Finally, four alternative combinations for the designed system are obtained:

(1) $S_1 = A_1 \star B_1 = (C_2 \star D_1 \star E_1 \star F_1) \star (G_1 \star I_1 \star J_1) = C_2 \star (X_2 \star Y_2) \star (U_1 \star V_1) \star (T_1 \star P_1 \star M_1) \star (Q_2 \star Z_1) \star (O_1 \star H_1) \star L_1 \star J_1$;

(2) $S_2 = A_2 \star B_1 = (C_2 \star D_2 \star E_1 \star F_1) \star (G_1 \star I_1 \star J_1) = C_2 \star (X_1 \star Y_1) \star (U_1 \star V_1) \star (T_1 \star P_1 \star M_1) \star (Q_2 \star Z_1) \star (O_1 \star H_1) \star L_1 \star J_1$;

(3) $S_3 = A_1 \star B_2 = (C_2 \star D_1 \star E_1 \star F_1) \star (G_2 \star I_1 \star J_1) = C_2 \star (X_2 \star Y_2) \star (U_1 \star V_1) \star (T_1 \star P_1 \star M_1) \star (Q_1 \star Z_1) \star (O_1 \star H_1) \star L_1 \star J_1$;

(4) $S_4 = A_2 \star B_2 = (C_2 \star D_2 \star E_1 \star F_1) \star (G_2 \star I_1 \star J_1) = C_2 \star (X_1 \star Y_1) \star (U_1 \star V_1) \star (T_1 \star P_1 \star M_1) \star (Q_1 \star Z_1) \star (O_1 \star H_1) \star L_1 \star J_1$.

Note, the initial set of possible solutions includes 82944 combinations.

IV. IMPROVEMENT/RECONFIGURATION

Generally, system improvement process can be based on the following methods (e.g., [9]):

(i) improvement of a system component (element),

(ii) improvement of compatibility between system components,

(iii) change a system structure, for example, extension of the system by addition of system components/parts.

Here, the system improvement (or reconfiguration) process is briefly presented as a combination of improvement actions by elements and improvement actions by compatibility. The illustrative improvement actions are presented in Table 3.

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TABLE III. BOTTLENECKS AND IMPROVEMENTS

Composite DAs	Bottlenecks		Improvement actions
	DA	IC	
$D_1 = X_2 \star Y_2$	X_2		$(1,3,0) \Rightarrow (4,0,0)$
$D_1 = X_2 \star Y_2$		(X_2, Y_2)	$2 \Rightarrow 3$
$D_2 = X_1 \star Y_1$	X_1		$(0,2,2) \Rightarrow (2,2,0)$
$D_2 = X_1 \star Y_1$	X_1		$(0,2,2) \Rightarrow (4,0,0)$
$D_2 = X_1 \star Y_1$	Y_2		$(3,1,0) \Rightarrow (4,0,0)$
$E_1 = U_1 \star V_1$	U_1		$(1,2,1) \Rightarrow (2,2,0)$
$E_1 = U_1 \star V_1$	U_1		$(1,2,1) \Rightarrow (4,0,0)$
$E_1 = U_1 \star V_1$	V_1		$(1,2,1) \Rightarrow (2,2,0)$
$E_1 = U_1 \star V_1$	V_1		$(1,2,1) \Rightarrow (4,0,0)$
$G_1 = Q_2 \star Z_1$	Q_2		$(2,2,0) \Rightarrow (4,0,0)$
$G_2 = Q_1 \star E_2$		(E_3, Z_1)	$2 \Rightarrow 3$
$G_2 = Q_1 \star Z_1$	Q_1		$(3,1,0) \Rightarrow (4,0,0)$
$G_2 = Q_1 \star Z_1$	Z_1		$(2,2,0) \Rightarrow (4,0,0)$
$K_1 = O_1 \star H_1$	O_1		$(2,2,0) \Rightarrow (4,0,0)$
$K_1 = O_1 \star H_1$	H_1		$(1,3,0) \Rightarrow (4,0,0)$

Further, the following improvement actions are examined (binary variables $\{y_{i,j}\}$ are used):

(1) Two versions for X_2: $y_{1,1}$ (none), $y_{1,2}$ ($(1,3,0) \Rightarrow (4,0,0)$);

(2) Two versions for (X_2, Y_2): $y_{2,1}$ (none), $y_{2,2}$ ($2 \Rightarrow 3$);

(3) Three versions for X_1: $y_{3,1}$ (none), $y_{3,2}$ ($(0,2,2) \Rightarrow (2,2,0)$); $y_{3,3}$ ($(0,2,2) \Rightarrow (4,0,0)$);

(4) Two versions for Y_2: $y_{4,1}$ (none), $y_{4,2}$ ($(3,1,0) \Rightarrow (4,0,0)$);

(5) Three versions for U_1: $y_{5,1}$ (none), $y_{5,2}$ ($(1,2,1) \Rightarrow (2,2,0)$), $y_{5,3}$ ($(1,2,1) \Rightarrow (4,0,0)$);

(6) Three versions for V_1: $y_{6,1}$ (none), $y_{6,2}$ ($(1,2,1) \Rightarrow (2,2,0)$), $y_{6,3}$ ($(1,2,1) \Rightarrow (4,0,0)$);

(7) Two versions for Q_2: $y_{7,1}$ (none), $y_{7,2}$ ($(2,2,0) \Rightarrow (4,0,0)$);

(8) Two versions for (Q_1, Z_1): $y_{8,1}$ (none), $y_{8,2}$ ($2 \Rightarrow 3$);

(9) Two versions for Q_1: $y_{7,1}$ (none), $y_{7,2}$ ($(3,1,0) \Rightarrow (4,0,0)$);

(10) Two versions for Z_1: $y_{10,1}$ (none), $y_{10,2}$ ($(2,2,0) \Rightarrow (4,0,0)$);

(11) Two versions for O_1: $y_{11,1}$ (none), $y_{11,2}$ ($(2,2,0) \Rightarrow (4,0,0)$);

(12) Two versions for H_1: $y_{12,1}$ (none), $y_{12,2}$ ($(1,3,0) \Rightarrow (4,0,0)$).

Table 4 contains binary variables (y_{ij}), improvement actions and their estimates (illustrative, expert judgment). As a result, the improvement problem is (q_j equals the number of corresponding versions):

$$\arg\min_{M \in D} \sum_{(i,j) \in S = \{(i,j) | y_{ij} = 1\}} |\delta(M, e_{ij})|,$$

$$s.t. \quad \sum_{i=1}^{12} \sum_{j=1}^{q_i} a_{ij} y_{ij} \le b; \quad \sum_{j=1}^{q_j} y_{ij} = 1;$$

$$y_{ij} \in \{0, 1\}. \qquad (5)$$

Some examples of the improvement solutions are (improvement problem corresponds to certain solution, i.e., S_1, S_2, S_3, S_4):

(1) S_1, $b = 41$: $y_{1,2} = 1$ (X_2, improvement 1), $y_{4,2} = 1$ (Y_2, improvement 1), $y_{8,2} = 1$ ((Q_1, Z_1), improvement 1); $y_{9,2} = 1$ (Q_1, improvement 1);

$S_1 \Rightarrow \widetilde{S_1} = C_2 \star (\widetilde{X_2 \star Y_2}) \star (U_1 \star V_1) \star (T_1 \star P_1 \star M_1) \star (\widetilde{Q_1 \star Z_1}) \star (O_1 \star H_1) \star L_1 \star J_1$;

(2) S_3, $b = 28$: $y_{1,2} = 1$ (X_2, improvement 1), $y_{4,2} = 1$ (Y_2, improvement 1), $y_{8,2} = 1$ ((Q_1, Z_1), improvement 1);

$S_3 \Rightarrow \widetilde{S_3} = C_2 \star (\widetilde{X_2 \star Y_2}) \star (U_1 \star V_1) \star (T_1 \star P_1 \star M_1) \star (Q_1 \star Z_1) \star (O_1 \star H_1) \star L_1 \star J_1$;

(3) S_4, $b = 43$: $y_{3,2} = 1$ (X_1, improvement 1), $y_{9,2} = 1$ (Q_1, improvement 1), $y_{10,2} = 1$, (Z_1, improvement 1);

$S_4 \Rightarrow \widetilde{S_4} = C_2 \star (\widetilde{X_1} \star Y_1) \star (U_1 \star V_1) \star (T_1 \star P_1 \star M_1) \star (\widetilde{Q_1} \star \widetilde{Z_1}) \star (O_1 \star H_1) \star L_1 \star J_1$.

TABLE IV. ESTIMATES OF IMPROVEMENTS

Improvement actions	Multiset estimate e_{ij}	Cost (a_{ij})
$y_{1,1}$ (X_2, None)	$(0,0,4)$	0
$y_{1,2}$ (X_2, Improvement 1)	$(4,0,0)$	10
$y_{2,1}$ ((X_2, Y_2), None)	$(0,0,4)$	0
$y_{2,2}$ ((X_2, Y_2), Improvement 1)	$(4,0,0)$	14
$y_{3,1}$ (X_1, None)	$(0,0,4)$	0
$y_{3,2}$ (X_1, Improvement 1)	$(2,2,0)$	10
$y_{3,3}$ (X_1, Improvement 2)	$(4,0,0)$	29
$y_{4,1}$ (Y_2, None)	$(0,0,4)$	0
$y_{4,2}$ (Y_2, Improvement 1)	$(4,0,0)$	9
$y_{5,1}$ (U_1, None)	$(0,0,4)$	0
$y_{5,2}$ (U_1, Improvement 1)	$(2,2,0)$	17
$y_{5,3}$ (U_1, Improvement 2)	$(4,0,0)$	30
$y_{6,1}$ (V_1, None)	$(0,0,4)$	0
$y_{6,2}$ (V_1, Improvement 1)	$(2,2,0)$	12
$y_{6,3}$ (V_1, Improvement 2)	$(4,0,0)$	24
$y_{7,1}$ (Q_2, None)	$(0,0,4)$	0
$y_{7,2}$ (Q_2, Improvement 1)	$(4,0,0)$	15
$y_{8,1}$ ((Q_1, Z_1), None	$(0,0,4)$	0
$y_{8,2}$ ((Q_1, Z_1), Improvement 1)	$(3,1,0)$	9
$y_{9,1}$ (Q_1, None)	$(0,0,4)$	0
$y_{9,2}$ (Q_1, Improvement 1)	$(4,0,0)$	13
$y_{10,1}$(Z_1, None)	$(0,0,4)$	0
$y_{10,2}$(Z_1, Improvement 1)	$(4,0,0)$	20
$y_{11,1}$(O_1, None)	$(0,0,4)$	0
$y_{11,2}$(O_1, Improvement 1)	$(4,0,0)$	18
$y_{12,1}$(H_1, None)	$(0,0,4)$	0
$y_{12,2}$(H_1, Improvement 1)	$(4,0,0)$	22

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V. Conclusion and Future Work

The paper describes a hierarchical approach to modular design of MPEG-like standard. Note, this material is a preliminary one and is based on illustrative estimates of design alternatives for elements of the standard (and estimates of compatibility between the design alternatives). The described illustrative solving schemes can be considered as prototype frameworks for real-world applications.

In the future, it may be prospective to consider the following research directions:

1. Consideration of other design and improvement (adaptation) problems in analysis and generation of communication standards;

2. Special simulation research to analyze various versions of communication standards;

3. Usage of AI techniques; and

4. Usage of the described application and design approach in engineering/CS education.

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