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Towards Morphological Design of GSM Network

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Abstract—The paper addresses hierarchical morphological modeling and design of GSM network. The tree-like structure of the system is considered and design alternative (DAs) for each system component (leaf node of the model) are generated. DAs are evaluated upon a set of criteria. Hierarchical Morphological Multicriteria Design (HMMD) approach is used: *1.* multicriteria analysis and ranking of alternatives (for leaf nodes of the hierarchical model) to get their ordinal priority on the basis of a common ordinal scale; *2.* combinatorial synthesis of composite alternatives while taking into account their priorities (i.e., ordinal quality) and their compatibility (evaluated upon ordinal scale). Electre-like outranking technique is used for multilcriteria ranking. Here Pareto-effective decisions are searching for in a discrete space of system excellence (i.e., quality of elements and quality of their compatibility). Combinatorial synthesis is based on enumerative directed algorithm or dynamic programming approach. The examined hierarchical method for GSM design may be useful in real-world network applications and in education.

1. INTRODUCTION

In recent decades, the significance of GSM network is increased (e.g., [12], [14], [17]). Thus there exists a need of the design and maintenance of this kind of communication systems. The design process consists often in finding a system configuration (i.e., realization of system parts, components). Generally, several basic approaches have been applied for the design of system configurations, for example: (i) multiple choice problem (e.g., [11], [16]), (ii) hierarchical multicriteria morphological design (HMMD) approach ([7], [8]), and (iii) AI methods [13].

In the paper, combinatorial synthesis as HMMD approach is used. The design problem is considered as analysis and composition of design alternatives (DAs) for system parts/components. HMMD approach involves two phases:

1. Multicriteria selection of alternatives for system parts. The stage is based on an outranking technique.

2. Composing the selected alternatives (DAs) into a resultant combination (while taking into account ordinal quality of the alternatives above and their compatibility or interconnection IC). Here Pareto-effective solutions/decisions are searching for in a discrete space of system excellence (i.e., quality of elements and quality of their compatibility).

Our numerical examples have illustrative character. The examined hierarchical method for GSM design may be useful in real-world network applications and in education.

2. SUPPORT PROBLEMS

2.1. Multiple Criteria Ranking

Multicriteria ranking of alternatives is a basic problem in decision making engineering. Let $H = \{1, ..., i, ..., t\}$ be a set of items which are evaluated upon criteria $K = \{1, ..., j, ..., d\}$ and $z_{i,j}$ is an estimate (quantitative, ordinal) of item i on criterion j. The matrix $\{z_{i,j}\}$ can be mapped into a partial order on H. The following partition as linear ordered subsets of H is searched for:

$$H = \cup_{k=1}^{m} H(k), \ |H(k_1) \cap H(k_2)| = 0 \ \ if \ \ k_1 \neq k_2,$$

$$i_2 \preceq i_1 \ \ \forall i_1 \in H(k_1), \ \forall i_2 \in H(k_2), \ k_1 \leq k_2.$$

Set $H(k)$ is called layer k, and each item $i \in H$ gets priority r_i that equals the number of the corresponding layer.

The list of basic techniques for multicriteria selection is the following [1]: (1) multi-attribute utility analysis [2]; (2) multi-criterion decision making [3] and multicriteria optimization [20]; (3) Analytic Hierarchy Process (AHP) [19]; and (4) outranking techniques (e.g., [18]). In the article an Electre-like outranking technique is used.

2.2. Hierarchical Morphological Multicriteria Design

Here we use Hierarchical Morphological Multicriteria Design (HMMD) on the basis of morphological clique problem ([5], [7], [8]). A brief description of HMMD is a typical one as follows ([5], [7], [8], [9], [10]). The examined composite (modular, decomposable) system consists of components and their interconnection (IC) or compatibility. 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; and *(d)* quality of system components and IC are evaluated on the basis of coordinated ordinal scales.

Here the designations are: (1) design alternatives (DAs) for leaf nodes of the model; (2) priorities of DAs ($r = 1, ..., k$; 1 corresponds to the best one); (3) ordinal compatibility (IC) for each pair of DAs ($w = 0, ..., l$, l corresponds to the best one).

The basic phases of HMMD are:

Phase 1. Design of the tree-like system model.

Phase 2. Generation of DAs for leaf nodes of the model.

Phase 3. Hierarchical selection and composing of DAs into composite DAs for the corresponding higher level of the system hierarchy.

Phase 4. Analysis and improvement of composite DAs (decisions).

Let S be a system consisting of m parts (components): $P(1), ..., P(i), ..., P(m)$. A set of design alternatives is generated for each system part above. Thus 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 $P(i)$, $i = 1, ..., m$) with non-zero IC between design alternatives.

A discrete space of the system excellence on the basis of the following vector is used: $N(S) = (w(S); n(S))$, where $w(S)$ is the minimum of pairwise compatibility between DAs which correspond to different system components (i.e., $\forall \ P_{j_1}$ and P_{j_2}, $1 \leq j_1 \neq j_2 \leq m$) in S, $n(S) = (n_1, ..., n_r, ...n_k)$, where n_r is the number of DAs of the rth quality in S.

As a result, we search for composite decisions which are nondominated by $N(S)$. Thus, the following layers of system excellence can be considered:

(i) ideal point;

(ii) Pareto-effective points; and

(iii) a neighborhood of Pareto-effective DAs (e.g., a composite decision of this set can be transformed into a Pareto-effective point on the basis of an improvement action(s)).

Clearly, the compatibility component of vector $N(S)$ can be considered on the basis of a poset-like scale too (as $n(S)$) [8]. In this case, the discrete space of system excellence will be an analogical lattice. Figs. 1 and 2 illustrate the composition problem. In the example, composite DAs is: $S_1 = X_2 \star Y_1 \star Z_2$, $N(S_1) = (1; 1, 1, 1)$. Discrete space of system quality is depicted in Figs. 3 and 4.

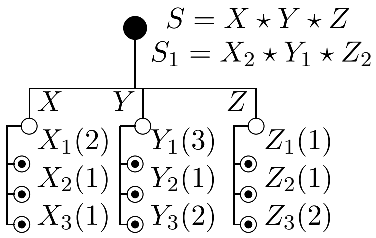

Fig. 1. Example of composition

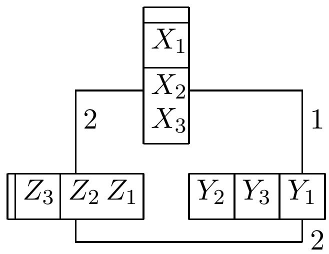

Fig. 2. Concentric presentation

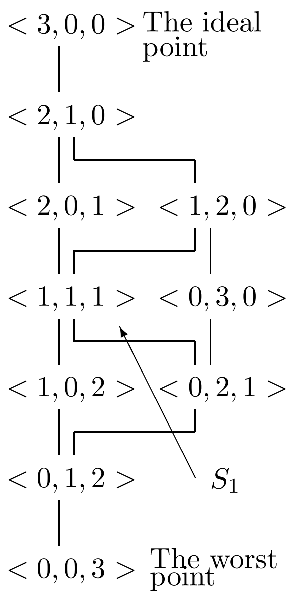

Fig. 3. Position (histogram) presentation of the lattice of system quality for $N = (w; n(1), n(2), n(3))$, w =const, $m = 3$, $l = 3$

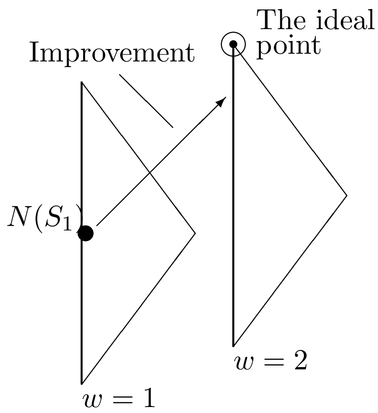

Fig. 4. Discrete space of system quality for $N(S)$

3. GSM NETWORK

3.1. Hierarchical Model and Components

The general tree-like simplified model of GSM network is as follows (Fig. 5, the developers of DAs are pointed out in parentheses):

0. GSM network $S = A \star B$.

1. Switching SubSystem SSS ($A = M \star L$).

1.1. Mobile Switching Center/Visitors Location Register MSC/VLR M : M_0 (Motorola), M_1 (Alcatel), M_2 (Huawei), M_3 (Siemens), and M_4 (Ericsson).

1.2. Home Location Register/Authentification Center HLR/AC L : L_0 (Motorola), L_1 (Ericsson), L_2 (Alcatel), and L_3 (Huawei).

2. Base Station SubSystem BSS ($B = V \star U \star T$).

2.1. Base Station Controller BSC V : V_0 (Motorola), V_1 (Ericsson), V_2 (Alcatel), V_3 (Huawei), V_4 (Nokia), and V_5 (Siemens).

2.2. Base Transceiver Station BTS U : U_0 (Motorola), U_1 (Ericsson), U_2 (Alcatel), U_3 (Huawei), and U_4 (Nokia).

2.3. Transceivers TRx T : T_0 (Alcatel), T_1 (Ericsson), T_2 (Motorola), T_3 (Huawei), and T_4 (Siemens).

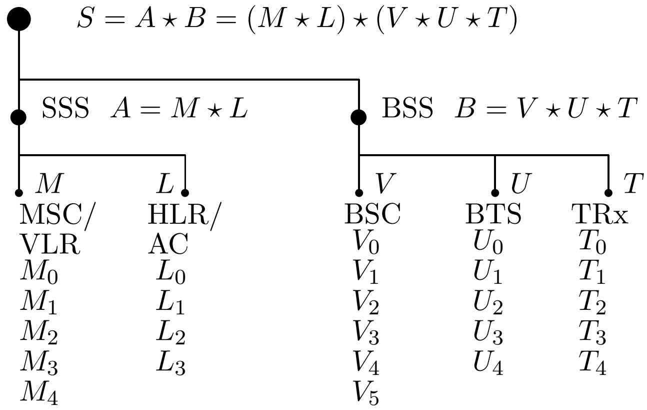

Fig. 5. General simplified structure of GSM network

3.2. Criteria, Estimate, Ranking, and Compatibility

Let us consider criteria for system components as follows (weights of criteria are pointed out in parentheses):

1. M: maximal number of datapathes E_1 (1000 tracts) (C_{m1}, 0.2); maximal capacity VLR (100000 subscribers) (C_{m2}, 0.2); price index (100000/price(USD)) (C_{m3}, 0.2); power consumption (1/power consumption (kWt)) (C_{m4}, 0.2); and number of communication and signaling interfaces (C_{m5}, 0.2).

2. L: maximal number of subsribers (100000 subscribers) (C_{l1}, 0.25); volume of service provided (C_{l2}, 0.25); reliability (scale $[1, ..., 10]$) (C_{l3}, 0.25); and integratability (scale $[1, ..., 10]$) (C_{l4}, 0.25).

3. V: price index (100000 / cost (USD))) (C_{v1}, 0.25); maximal number of BTS (C_{v2}, 0.25); handover quality (C_{v3}, 0.25); and throughput (C_{v4}, 0.25).

4. U: maximal number of TRx (C_{u1}, 0.25); capacity (C_{u2}, 0.25); price index (100000 / cost(USD)) (C_{u3}, 0.25); and reliability (scale $[1, ..., 10]$) (C_{u4}, 0.25).

5. T: maximum power-carrying capacity (C_{t1}, 0.3); throughput (C_{t2}, 0.2); price index (100000/cost(USD)) (C_{t3}, 0.25); and reliability (scale $[1, ..., 10]$) (C_{t4}, 0.25).

Note an attempt of generalized examination of requirements/criteria for communication networks is contained in ([4], [10]). Table 1, 2, 3, 4, and 5 contained estimates of DAs upon criteria above and their resultant priorities. Estimates of compatibility between DAs (expert judgment) are contained in Table 6 and 7.

Table 1. Estimates for M

DAs	Criteria					Priority
	C_{m1}	C_{m2}	C_{m3}	C_{m4}	C_{m5}	
M_0	3.7	8.6	6	5.1	4	2
M_1	4.0	11	8	7	5	3
M_2	4.1	10	9	7	4	3
M_3	3.2	7	5	6	3	1
M_4	3.5	8.7	6.2	5	4	2

Table 2. Estimates for L

DAs	Criteria				Priority
	C_{l1}	C_{l2}	C_{l3}	C_{l4}	
L_0	9	7	7	8	1
L_1	10	4	9	8	1
L_2	12	8	10	10	2
L_3	9	5	8	8	1

Table 3. Estimates for V

DAs	Criteria				Priority
	C_{v1}	C_{v2}	C_{v3}	C_{v4}	
V_0	6	4	3	4	1
V_1	7	5	7	7	2
V_2	9	7	10	7	3
V_3	7	5	8	6	2
V_4	6	3	4	4	1
V_5	10	6	9	7	3

Table 4. Estimates for U

DAs	Criteria				Priority
	C_{u1}	C_{u2}	C_{u3}	C_{u4}	
U_0	2	7	5	8	1
U_1	4	10	6	10	3
U_2	3	9	6	10	2
U_3	3	6	3	7	1
U_4	3	10	6	9	2

Table 5. Estimates for T

DAs	Criteria				Priority
	C_{t1}	C_{t2}	C_{t3}	C_{t4}	
T_0	9	7	10	7	3
T_1	6	4	3	4	1
T_2	7	5	7	7	2
T_3	7	5	8	6	2
T_4	6	3	4	4	1

3.3. Composite Decisions

For system part A, we get the following Pareto-effective composite DAs:

(1) $A_1 = M_3 \star L_1$, $N(A_1) = (3; 2, 0, 0)$; (2) $A_2 = M_3 \star L_3$, $N(A_2) = (3; 2, 0, 0)$.

For system part B, we get the following Pareto-effective composite DAs:

(1) $B_1 = V_4 \star U_0 \star T_4$, $N(B_2) = (2; 3, 0, 0)$; (2) $B_2 = V_4 \star U_3 \star T_1$, $N(B_3) = (2; 3, 0, 0)$; and (3) $B_3 = V_0 \star U_4 \star T_0$, $N(B_5) = (3; 1, 1, 1)$.

Space of system quality for B is depicted in Fig. 6.

Now it is possible to combine the resultant composite DAs as follows:

(1) $S_1 = A_1 \star B_1 = (M_3 \star L_1) \star (V_4 \star U_0 \star T_4)$; (2) $S_2 = A_1 \star B_2 = (M_3 \star L_1) \star (V_4 \star U_3 \star T_1)$;
(3) $S_3 = A_1 \star B_3 = (M_3 \star L_1) \star (V_0 \star U_4 \star T_0)$; (4) $S_4 = A_2 \star B_1 = (M_3 \star L_3) \star (V_4 \star U_0 \star T_4)$;
(5) $S_5 = A_2 \star B_2 = (M_3 \star L_3) \star (V_4 \star U_3 \star T_1)$; and (6) $S_6 = A_2 \star B_3 = (M_3 \star L_3) \star (V_0 \star U_4 \star T_0)$.

The composite decisions are depicted in Fig. 7 ($\{S_1, S_2, S_3, S_4, S_5, S_6\}$) and can be analyzed to select the best decision (e.g., additional multicriteria analysis, expert judgment). Note an initial set of possible composite decisions contained 3000 combinations ($5 \times 4 \times 6 \times 5 \times 5$).

Table 7. Compatibility

	U_0	U_1	U_2	U_3	U_4	T_0	T_1	T_2	T_3	T_4
V_0	2	2	2	2	3	3	2	2	2	2
V_1	3	3	3	2	1	1	3	1	3	2
V_2	3	3	3	2	1	1	3	1	3	2
V_3	3	2	1	2	3	1	2	1	2	2
V_4	3	1	1	2	1	2	2	1	2	2
V_5	1	3	2	3	2	3	1	2	2	1
U_0						2	1	1	2	3
U_1						1	2	1	3	1
U_2						1	2	1	3	1
U_3						1	3	3	1	1
U_4						3	1	2	2	1

Table 6. Compatibility

	L_0	L_1	L_2	L_3
M_0	3	2	1	3
M_1	2	3	2	1
M_2	1	2	3	2
M_3	2	3	3	3
M_4	3	3	1	3

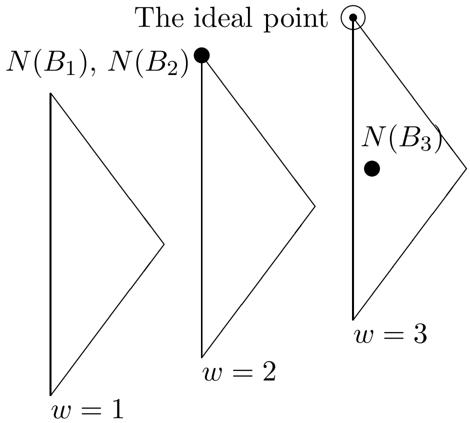

Fig. 6. Space of system quality for B

3.4. Bottlenecks and Improvement

It is reasonable to consider additional technological system problems ([8], [10]): (a) revelation of "bottlenecks"and (b) improvement of the obtained solution(s). For example, let us examine composite DAs for B (Table 8). A set of improvement actions (operations) is obtained (Table 8, improvement actions for DAs or IC are denoted by symbol $\Rightarrow$).

4. CONCLUSION

In the paper, the combinatorial hierarchical approach to the composition of components in the design of GSM system has been described. The material has a preliminary character. Clearly, it is reasonable to consider the following future research directions: *1.* extension of the considered architecture for GSM system and examination of real-world applications; *2.* analyzing some issues of system improvement, adaptability and upgrade-ability; *3.* consideration of multi-stage design or design of a system trajectory; and *4.* usage of fuzzy set approaches and AI techniques.

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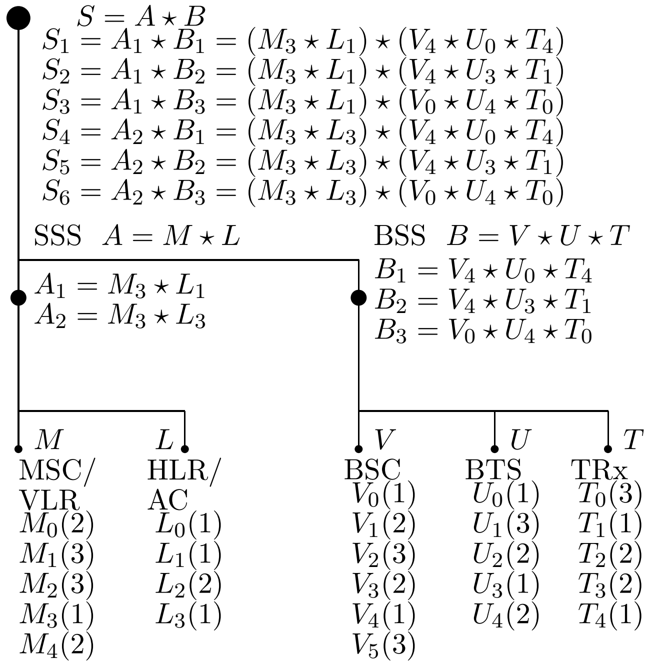

Fig. 7. Designed GSM network (priorities of DAs are shown in parentheses)

Table 8. Bottlenecks and improvement actions

Composite DAs	Bottlenecks		Actions w/r
	DAs	IC	
$B_1 = V_4 \star U_0 \star T_4$		(V_4, T_4)	$2 \Rightarrow 3$
$B_2 = V_4 \star U_3 \star T_1$		(V_4, U_3)	$2 \Rightarrow 3$
$B_2 = V_2 \star U_3 \star T_1$		(V_4, T_1)	$2 \Rightarrow 3$
$B_3 = V_0 \star U_4 \star T_0$	U_4		$2 \Rightarrow 1$

REFERENCES

1. Buede D.M., Software review. Overview of MCDA software market. *J. of Multi-Criteria Decision Analysis*, 1992, vol. 1, no. 1, pp. 59–61.

2. Keeny R.L., Raiffa H., *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, New York: J.Wiley & Sons, 1976.

3. Korhonen P., Wallenius J., Zionts S., Solving the discrete multiple criteria problems using convex cones. *Manag. Sci.*, 1984, vol. 30, no. 11, pp. 1336–1345.

4. Kuznetsov N.A., Levin M.Sh., Vishnevsky V.M., Some combinatorial optimization schemes for multi-layer network topology. *Electronic Proc. of 17th IMACS World Congress*, France, Paper T4-I-42-0486, 2005.

5. Levin M.Sh., *Combinatorial Engineering of Decomposable Systems*, Dordrecht: Kluwer Academic Publishers, 1998.

6. Levin M.Sh., Course "Design of Systems: Structural Approach"(2004...2007) http://www.iitp.ru/mslevin/SYSD.HTM

7. Levin M.Sh., Modular system synthesis: Example for composite packaged software. *IEEE Trans. on SMC, Part C*, 2005, vol. 35, no. 4, pp. 544–553.

8. Levin M.Sh., *Composite Systems Decisions.* New York: Springer, 2006.

9. Levin M.Sh., Course 'System design: structural approach'. *18th Int. Conf. Design Methodology and Theory DTM2006*, DETC2006-99547, 2006.

10. Levin M.Sh., Combinatorial technological systems models (Examples for communication system). *2nd Int. Conf. on Systems Engineering and Modeling*, Haifa, 2007, pp. 24-32.

11. Levin M.Sh., Safonov A.V., Design and redesign of configuration for facility in communication network. *Information Technologies and Computer Systems,* 2006, no 4, pp. 63-73 (in Russian).

12. Lin. Y.-B., OA&M for GSM network. *IEEE Network*, 1997, vol. 11, no. 2, pp. 46-57.

13. McDermott J., R1: a rule-based configurer of computer systems. *Artificial Intelligence,* 1982, vol. 19, no. 2, pp. 39–88.

14. Mehrotra A., *GSM System Engineering*, Boston: Artech House, 1997.

15. Netcracker, Inc. http: //www.netcracker.com

16. Poladian V., Sousa J.P., Garlan D., Schmerl B., Shaw M., Task-based adaptation for ubiquitous computing. *IEEE Trans. on SMC - Part C,* 2006, vol. 36, no. 3, pp. 328–340.

17. Rahnema M., Overview of the GSM systems and protocol architecture. *IEEE Communication Magazine*, 1993, vol. 31, no. 4, pp. 92-100.

18. Roy B., *Multicriteria Methodology for Decision Aiding*, Dordrecht: Kluwer Academic Publishers, 1996.

19. Saaty T.L., *The Analytic Hierarchy Process*, New York: MacGraw-Hill, 1988.

20. Steuer R.L., *Multiple Criteria Optimization: Theory, Computation, and Application*, New York: J.Wiley & Sons, 1986.