Philippine Engineering Journal (1996) XVII (2): 1 - 28

CODING TELEPHONE NUMBERS TO AVOID "WRONG NUMBERS"

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ABSTRACT

"Wrong numbers" are an annoyance for owners of telephones. These incidents are due to several causes, of which the following two may be the most common: (a) pressing the wrong button on a telephone keypad, or (b) misreading a printed or handwritten telephone number.

This paper presents two methods for developing numbering plans that will reduce the incidence of accidental wrong numbers when using push-button telephone sets by utilizing an error-detecting code on telephone numbers. It is demonstrated that small telephone numbering plans for 2 digits to 4 digits can be quickly generated by using a weighted code or by exhaustive search. Rotary dial phones are not considered in the paper.

INTRODUCTION

"Wrong numbers" are incidents in which an unintended telephone number is dialed and caused to ring. Except for technical problems with the telephone set or switch, wrong numbers are the result of the caller dialing an incorrect telephone number. The most probable causes of such incidents are: (a) pressing the wrong button on a telephone keypad by mistake, or (b) misreading a printed or handwritten telephone number.

In typical telephone numbering plans for PABX systems, digits (or ranges of digits) are assigned for different purposes. For example, "0" is commonly assigned to the operator (attendant), and "9" is assigned for outside lines. In large organizations, the remaining digits are commonly assigned by physical location or by organizational unit. For example, a multistory building, telephones on the first floor can begin "1", telephones on the second floor can begin with "2", and so on. Within each floor, telephone numbers will be assigned sequentially, such as "100,""101," "102," etc. This kind of numbering plan is susceptible to wrong numbers because every number within a given range can be assigned to a telephone line.

In old electromechanical and stored program control (SPC) telephone switches, one telephone number was permanently assigned to each telephone line, so it was necessary to use telephone numbers in numeric sequence. However, modern computerized exchanges provide a logical (i.e., software) assignment of telephone numbers to physical lines. This allows telephone numbers to be assigned more creatively.

This paper presents two methods for developing numbering plans that will reduce the incidence of accidental wrong numbers when using push-button telephone sets by utilizing an error-detecting code on telephone numbers. Error codes make two telephone numbers sufficiently different that an unintentional change of one digit due to either cause mentioned above will not result in a valid but unintended telephone number (i.e., a "wrong number"). Instead, if an invalid telephone number is mistakenly dialed, the caller will get a busy tone or other indication that the number dialed is not in service.

The paper is organized as follows. First, the concepts of distance between digits and the distance matrix are introduced. Second, the application of weighted codes to telephone numbers is discussed. Third, several larger numbering plans obtained by exhaustive search are presented. Finally, the possibility of detecting all single-digit dialing errors is considered.

The conclusions in this paper are limited to telephone sets with push-button (or keypad) dial, whether they be of the DTMF or pulse dial kind, although the same concepts can be applied just as easily to rotary dial telephone sets.

THE TELEPHONE KEYPAD

The conventional telephone keypad for push-button telephones consists of digits "0" to "9" and the symbols "*" and "#" arranged in a 4 x 3 array as shown in Figure 1. In this keypad, a dialing error may occur when the button that is pressed is physically adjacent to the one intended.

We assume that it is more likely to misdial an adjacent digit than a digit positioned farther away from the intended one. The physical proximity or *distance* of digits can be quantified by the

1	2	3
4	5	6
7	8	9
*	0	#

Figure 1. The telephone keypad

number of buttons separating the two digits. Thus digits "1" and "2" are separated by a distance of 1 because they are adjacent. The same is true for digits "1" and "5". On the other hand, digits "1" and "9" are separated by a distance of 2. The same is true for digits "1" and "7".

Verhoeff [4] mentions that a study of 12,000 keying errors found the following percentages for various kinds of keying errors:

single errors a → b	60% to 95% of all errors
adjacent transpositions ab → ba	10% to 20% of all errors
omitting or adding a digit	10% to 20% of all errors
twin errors aa → bb	0.5% to 1.5% of all errors

Other types of keying errors mentioned in this reference are found in at most 1.5% of all errors. Thus, the first two types of errors have the greatest contribution to wrong number incidents in telephone systems, and are considered in this paper. The third type does not usually result in a wrong number because telephone numbers have a fixed length.

	DIGIT									
	1	2	3	4	5	6	7	8	9	0
digit 1	0	1	2	1	1	2	2	2	2	3
digit 2	1	0	1	1	1	1	2	2	2	3
digit 3	2	1	0	2	1	1	2	2	2	3
digit 4	1	1	2	0	1	2	1	1	2	2
digit 5	1	1	1	1	0	1	1	1	1	2
digit 6	2	1	1	2	1	0	2	1	1	2
digit 7	2	2	2	1	1	2	0	1	2	1
digit 8	2	2	2	1	1	1	1	0	1	1
digit 9	2	2	2	2	1	1	2	1	0	1
digit 0	3	3	3	2	2	2	1	1	1	0

Figure 2. A basic distance matrix showing physical distances in the telephone keypad.

Distance between pairs of digits are conveniently displayed in the form of a symmetrical *distance matrix* in which the i -jth element represents the distance between digit "i" and digit "j". For indexing purposes in the distance matrix, button "0" is represented by index 10. The buttons "*" and "#" may be ignored because they are not used in telephone numbers. (However, they may be used in feature codes that initiate special telephone operations.) Figure 2 shows the basic distance matrix for the telephone keypad.

Rotary dial telephones have a different arrangement of the digits 0 to 9. Hence the distance matrix for rotary dial telephones is different, and will not be considered in this paper.

TRANSCRIPTION ERRORS

Besides the mechanical error of pressing the wrong button, another cause of wrong numbers is misreading or miscopying of a written telephone number. This is due to the similarity of certain pairs of digits when they are typed or handwritten, such as the following: (Henceforth, for brevity, these will be called "similar digits.")

1,7	5,6
2,7	6,0
3,8	9,0
4,7	

	DIGIT 1	2	3	4	5	6	7	8	9	0
digit 1	0	1	2	1	1	2	1	2	2	3
digit 2	1	0	1	1	1	1	1	2	2	3
digit 3	2	1	0	2	1	1	2	1	2	3
digit 4	1	1	2	0	1	2	1	1	2	2
digit 5	1	1	1	1	0	1	1	1	1	2
digit 6	2	1	1	2	1	0	2	1	1	1
digit 7	1	1	2	1	1	2	0	1	2	1
digit 8	2	2	1	1	1	1	1	0	1	1
digit 9	2	2	2	2	1	1	2	1	0	1
digit 0	3	3	3	2	2	1	1	1	1	0

Figure 3. A modified distance matrix for the telephone keypad representing similar digits.

These pairs of digits may be thought of as being adjacent in an abstract space of digits. Adjacent digits, whether due to physical proximity or similarity, are susceptible to misdialing errors. This condition is represented by placing a distance of 1 for these digit pairs in the distance matrix. The resulting modified distance matrix appears in Figure 3.

Wrong numbers can also result from phonetic errors in dictating a telephone number. For example, the English words "thirty" and "thirteen" sound alike, Verhoeff [4] reports that phonetic errors accounted for 0.5% to 1.5% of a sample of 12,000 errors. This kind of error is not studied in this paper.

THE DISTANCE OF TELEPHONE NUMBERS

The *distance* between two telephone numbers is defined as the sum of distances of pairs of digits, according to some distance matrix. For example, given two 3-digit telephone numbers $a_1a_2a_3$ and $b_1b_2b_3$, the distance **D** is computed as

$$D = \sum_i d(a_i, b_i)$$

where $d(a_i, b_i)$ is the i - jth element of the distance matrix.

The *distance* **D** expresses the similarity of two telephone numbers, and thus their susceptibility to be mistakenly exchanged. We consider that two telephone numbers with a distance of one are more likely to be mistaken for each other than two numbers with a distance of two between them. This measure is similar to the concept of *Hamming distance* applied to binary codes [2,3].

The basic idea to avoid wrong numbers is that no two telephone numbers in use should have a distance of one, because this will allow a mistake in one digit to result in another valid telephone number (a "wrong number"). When a distance greater than 1 is involved, a more serious type of error is required in order to reach another valid number. An example is pressing digit "3" instead of digit "1", another is misreading "1" as "7". Thus, the minimum distance between valid telephone numbers in a numbering plan should be at least two in order to reduce incidences of wrong numbers.

The succeeding sections discuss two different ways to generate numbering plans that conform with this condition.

WEIGHTED CODES

A weighted code adds one *check digit* or check symbol to the basic telephone number. The check digit is computed using decimal or modular arithmetic operations. These kinds of codes are commonly found in the literature [2,5].

As an example, for a 3-digit telephone number with a modulus 5 check digit, the defining equation for an acceptable telephone number $a_1 a_2 a_3$ is

$$4a_1 + 2a_2 + a_3 = 0 \pmod 5$$

Here the check digit is a_3, the *digit weights* are 1, 2, and 4 and the *modulus* is 5. Digits 0 to 9 carry their respective numerical values for purposes of the above computation. Basically, the equation requires the left hand side to be exactly divisible by the modulus. This check method yields 200 acceptable telephone numbers listed in Table 1, or 20% of the 1,000 possible 3-digit combinations. The distance between any two numbers in this table (computed according to the basic distance matrix of Figure 2) is greater than one, which means that replacement of any digit by a physically adjacent digit can be detected. However, an exchange of two digits (transposition) may not always be detected. Specifically, if two digits differing by 5 are exchanged, the resulting telephone number is also found in Table 1.

One drawback of the numbering plan in Table 1 is that similar digits can cause wrong numbers. For example, telephone number "122" can be misread as "127" due to similarity of the rightmost digits.

A different choice of modulus and digit weights yields the numbering plan in Table 2 in which misdialing an adjacent or similar digit will not result in a wrong number. Here the modulus is 7 and the digit weights are 1, 3 and 5. For purposes of computation, digit "0" is assigned a numerical value of 10. The other digits carry their ordinary numerical values. This check method yields 143 acceptable telephone numbers listed in Table 2, or 1/7 of all the possible 3-digit combinations. The distance between any two numbers in this table (computed according to the modified distance matrix of Figure 3) is greater than one, which means that replacement of any digit by an adjacent or a similar digit can be detected. For this check, only 6.2% of digit exchange errors (transpositions) will result in wrong numbers.

In actual use, some of the telephone numbers listed in Table 1 and 2 will be excluded by the numbering plan. (For example, "0" for operator and "9" for outside line excludes telephone numbers beginning with those digits.) Thus, the actual count of available telephone numbers will be somewhat less. Nevertheless, the remaining numbers are sufficient when the number of lines in a telephone system do not exceed about 160 for Table 1 or 114 for Table 2.

In a 4-digit numbering plan, a modulus of 7 and digit weights of 1,3 and 5 as above generate less than 1,430 telephone numbers using the basic distance matrix of Figure 3 (including numbers beginning with "9" and "0"), which is adequate for many installations. However, in a 2-digit numbering plan, only 14 numbers can be generated, which do not constitute a practical telephone numbering plan.

A weighted code with well-chosen digit weights and a prime modulus larger than 9 will theoretically detect all changes in one digit position, as well as all exchanges (or transpositions) of two digit positions [1,2]. Both of these are common errors in dialing a telephone number. However, we want the check digit to be one of the digits 0 to 9, so the choices of modulus are narrowed to 3,5,7 or 10 (not prime).

For the basic distance matrix of Figure 2, the combinations given in Figure 4 produce workable 3-digit numbering plans that will detect replacement of any digit by an adjacent digit on the telephone keypad.

Modulus	Digit Weights	Usable Telephone Numbers
5	1,2,4	200
5	1,3,7	200
10	1,2,4	100
10	1,3,7	100

Figure 4. Modulus and digit weight assignments for weighted codes that detect replacement of a digit by an adjacent digit on the telephone keypad.

However, for the modified distance matrix of Figure 3, a smaller number of combinations are found to be acceptable. The two listed in Figure 5, will detect replacement of any digit by an adjacent or similar digit. The second combinations can produce a mere 100 usable telephone numbers.

Reference [5] reviews other check digit schemes based on more complex calculations, including table lookup.

Modulus	Digit Weights	Usable Telephone Numbers	Comment
7	1,3,5	143	Value of digit "0" = 10
10	1,3,7	100	Value of Digit "0" = 0

Figure 5. Modulus and digit weight assignments for weighted codes that detect replacement of a digit by an adjacent or similar digit.

LARGER NUMBERING PLANS

To be able to detect single digit errors and some digit exchange errors, weighted codes eliminate the majority of possible telephone numbers (i.e. the combinations of the digits 0 to 9). This is consistent with the idea that an error detecting code should use only a small fraction of available symbol combinations as codewords so that a random error is unlikely to result in a valid codeword. For example, it was observed earlier that the various numbering plans using 3-digit weighted codes contain anywhere from 10% to 20% of all 3-digit combinations. This may not leave enough valid telephone numbers in the numbering plan for installations with a large number of telephone lines.

In order to generate more telephone numbers, we have to give up something. For example, we can trade off the ability to detect digit exchange errors for additional telephone numbers. In a few minutes or less on a personal computer, a brute force exhaustive search over the space of telephone numbers can generate a maximal subset in which telephone numbers are spaced by a distance of two or more. For example, a 3-digit numbering plan is generated by starting with all 1,000 numbers from "000" to "999," and deleting those numbers that have a Hamming distance of 1 from already selected numbers. What is left forms a numbering plan with the ability to detect single-digit dialing errors.

The subsequent tables (Tables 3 to 6) present several different numbering plans with this property, for lengths ranging from 2 digits to 4 digits, obtained by exhaustive search.

Table 3 lists two different sets of 2-digit telephone numbers that can be used in small organizations. The numbering plan in Table 3a is capable of detecting a change in one digit by an adjacent digit. In addition to this capability, the numbering plan in Table 3b can detect substitution by a similar digit, according to the distance matrix of Figure 3.

Tables 4 and 5 present the 3-digit numbering plans. With the basic distance matrix of Figure 2, between 25% to 30% of all the digit combinations are available to be used. The listing in Table 4 contains 268 acceptable numbers versus the 200 generated by the weighted code in Table 1. This can detect a change in one digit by an adjacent digit. The second numbering plan in Table 5 contains 192 numbers versus the 143 generated by the weighted code in Table 2. This plan can detect a substitution of one digit by a similar digit. Exhaustive search has found about 34% more acceptable combinations compared to more systematic weighted code.

Table 6 presents a 4-digit telephone numbering plan that avoids adjacent and similar digits. The modified distance matrix of Figure 3 is used here. Less than 18% of all 4-digit combinations are eligible to be used. This is still more than the 1,430 telephone numbers generated by the weighted code. If the basic distance matrix of Figure 2 is used instead, there are 2,568 telephone numbers available.

DETECTING SINGLE-DIGIT ERRORS

We might wish to require a numbering plan that avoids all instances of wrong numbers due to incorrect dialing of one digit only (i.e. not just adjacent digits or similar digits). For example, instead of dialing "111," the number "110" might be incorrectly dialed. This requirement can be accommodated by modeling all of the digits to be logically adjacent to each other in the abstract number space. Then the distance matrix contains zeros along the diagonal and unity for all non-diagonal elements.

A brute force exhaustive search yields the following sizes for the resulting numbering plans:

- 2-digit numbering plan -- 10 telephone numbers
- 3-digit numbering plan -- 76 telephone numbers
- 4-digit numbering plan -- 712 telephone numbers

It appears that the requirement to detect all single-digit dialing errors is too restrictive and results in a very small numbering plan that is not practical to use. For example, 76 telephones can be accommodated by a 2-digit telephone number, albeit without any protection against wrong numbers. Thus, the 3-digit error-detecting numbering plan is longer by one extra digit.

CONCLUSIONS

This paper has presented two methods for developing numbering plans that will reduce the incidence of accidental wrong numbers when using push-button telephone sets. One set of numbering plans is generated by treating a telephone number as a weighted code with a check digit. These are relatively easy to generate by using the defining equation for a valid digit combination (i.e. "codeword"). However, for 2 to 4 digit telephone numbers, the weighted code only generates small numbering plans.

The second set of numbering plans is generated by an exhaustive search of the telephone number spaces for 2 digits to 4 digits. These contain significantly more usable numbers. For 3 digits, there are 34% more telephone numbers found by exhaustive search than are generated by a weighted code.

One drawback of these numbering plans is that telephone numbers are not sequential. This gives difficulties to system administrators in generating and assigning telephone numbers, and to users in remembering them.

Finally, the possibility of detecting all single-digit dialing errors does not seem to be practical because the telephone number would have to be increased by one extra digit.

Rotary dials commonly found on pulse dial telephone sets have a different physical layout of the digits 0 to 9. Numbering plans that avoids adjacent digit or similar digit dialing errors can be similarly generated by modifying the distance matrices in Figures 2 and 3. However, this is not considered in this paper.

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Table 1.
Modulus 5 weighted code with digit weights of 1, 2 and 4 using the basic distance matrix of Fig. 2.

1	000
2	005
3	013
4	018
5	021
6	026
7	034
8	039
9	042
10	047
11	050
12	055
13	063
14	068
15	071
16	076
17	084
18	089
19	092
20	097
21	101
22	106
23	114
24	119
25	122
26	127
27	130
28	135
29	143
30	148
31	151
32	156
33	164
34	169
35	172
36	177
37	180
38	185
39	193
40	198
41	202
42	207
43	210
44	215
45	223
46	228
47	231
48	236
49	244
50	249
51	252
52	257
53	260
54	265
55	273
56	278
57	281
58	286
59	294
60	299
61	303
62	308
63	311
64	316
65	324
66	329
67	332
68	337
69	340
70	345
71	353
72	358
73	361
74	366
75	374
76	379
77	382
78	387
79	390
80	395
81	404
82	409
83	412
84	417
85	420
86	425
87	433
88	438
89	441
90	446
91	454
92	459
93	462
94	467
95	470
96	475
97	483
98	488
99	491
100	496
101	500
102	505
103	513
104	518
105	521
106	526
107	534
108	539
109	542
110	547
111	550
112	555
113	563
114	568
115	571
116	576
117	584
118	589
119	592
120	597
121	601
122	606
123	614
124	619
125	622
126	627
127	630

128	635
129	643
130	648
131	651
132	656
133	664
134	669
135	672
136	677
137	680
138	685
139	693
140	698
141	702
142	707
143	710
144	715
145	723
146	728
147	731
148	736
149	744
150	749
151	752
152	757
153	760
154	765
155	773
156	778
157	781
158	786
159	794
160	799
161	803
162	808
163	811
164	816
165	824
166	829
167	832
168	837
169	840
170	845
171	853
172	858
173	861
174	866
175	874
176	879
177	882
178	887
179	890
180	895
181	904
182	909
183	912
184	917
185	920
186	925
187	933
188	938
189	941
190	946
191	954
192	959
193	962
194	967
195	970
196	975
197	983
198	988
199	991
200	996

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Table 2.
Modulus 7 weighted code with digit weights of 1, 3 and 5 using the modified distance matrix of Fig. 3.

1	116
2	123
3	120
4	137
5	144
6	151
7	158
8	165
9	172
10	179
11	186
12	193
13	190
14	107
15	211
16	218
17	225
18	232
19	239
20	246
21	253
22	250
23	267
24	274
25	281
26	288
27	295
28	202
29	209
30	313
31	310
32	327
33	334
34	341
35	348
36	355
37	362

38	369
39	376
40	383
41	380
42	397
43	304
44	415
45	422
46	429
47	436
48	443
49	440
50	457
51	464
52	471
53	478
54	485
55	492
56	499
57	406
58	517
59	524
60	531
61	538
62	545
63	552
64	559
65	566
66	573
67	570
68	587
69	594
70	501
71	508
72	612
73	619
74	626
75	633
76	630
77	647
78	654
79	661
80	668
81	675
82	682
83	689
84	696
85	603
86	600
87	714
88	721
89	728
90	735
91	742
92	749
93	756
94	763
95	760
96	777
97	784
98	791
99	798
100	705
101	816
102	823
103	820
104	837
105	844
106	851
107	858
108	865
109	872
110	879
111	886
112	893
113	890
114	807
115	911
116	918
117	925
118	932
119	939
120	946
121	953
122	950
123	967
124	974
125	981
126	988
127	995
128	902
129	909
130	013
131	010
132	027
133	034
134	041
135	048
136	055
137	062
138	069
139	076
140	083
141	080
142	097
143	004

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Table 3a.
2-digit telephone numbers with minimum distance of 2 using the basic distance matrix of Fig. 2.

1	11
2	13
3	17
4	19
5	22
6	28
7	31
8	33
9	37
10	39
11	44
12	46
13	40
14	55
15	64
16	66
17	60
18	71
19	73
20	77
21	79
22	82
23	88
24	91
25	93
26	97
27	99
28	04
29	06
30	00

--o0o--

Table 3b.
2-digit telephone numbers with minimum distance of 2 using the modified distance matrix of Fig. 3.

1	11
2	13
3	18
4	22
5	29
6	31
7	33
8	38
9	44
10	46
11	40
12	55
13	64
14	66
15	60
16	77
17	81
18	83
19	88
20	92
21	99
22	04
23	06
24	00

--o0o--

Table 4.
3-digit telephone numbers with minimum distance of 2 using the basic distance matrix of Fig. 2.

1	111
2	113
3	117
4	119
5	122
6	128
7	131
8	133
9	137
10	139
11	144
12	146
13	140
14	155
15	164
16	166
17	160
18	171
19	173
20	177
21	179
22	182
23	188
24	191
25	193
26	197
27	199
28	104
29	106
30	100
31	212
32	218
33	221
34	223
35	227
36	229
37	232
38	238
39	245
40	254
41	256
42	250
43	265
44	272
45	278
46	281
47	283
48	287
49	289
50	292
51	298
52	205
53	311
54	313
55	317
56	319
57	322
58	328
59	331
60	333
61	337
62	339
63	344
64	346
65	340
66	355
67	364
68	366
69	360
70	371
71	373
72	377
73	379
74	382
75	388
76	391
77	393
78	397
79	399
80	304
81	306
82	300
83	414
84	416
85	410
86	425
87	434
88	436
89	430
90	441
91	443
92	447
93	449
94	452
95	458
96	461
97	463
98	467
99	469
100	474
101	476
102	470
103	485
104	494
105	496
106	490
107	401
108	403
109	407
110	409
111	515
112	524
113	526
114	520
115	535
116	542
117	548
118	551
119	553
120	557
121	559
122	562
123	568
124	575
125	584
126	586
127	580

128	595
129	502
130	508
131	614
132	616
133	610
134	625
135	634
136	636
137	630
138	641
139	643
140	647
141	649
142	652
143	658
144	661
145	663
146	667
147	669
148	674
149	676
150	670
151	685
152	694
153	696
154	690
155	601
156	603
157	607
158	609
159	711
160	713
161	717
162	719
163	722
164	728
165	731
166	733
167	737
168	739
169	744
170	746
171	740
172	755
173	764
174	766
175	760
176	771
177	773
178	777
179	779
180	782
181	788
182	791
183	793
184	797
185	799
186	704
187	706
188	700
189	812
190	818
191	821
192	823
193	827
194	829
195	832
196	838
197	845
198	854
199	856
200	850
201	865
202	872
203	878
204	881
205	883
206	887
207	889
208	892
209	898
210	805
211	911
212	913
213	917
214	919
215	922
216	928
217	931
218	933
219	937
220	939
221	944
222	946
223	940
224	955
225	964
226	966
227	960
228	971
229	973
230	977
231	979
232	982
233	988
234	991
235	993
236	997
237	999
238	904
239	906
240	900
241	014
242	016
243	010
244	025
245	034
246	036
247	030
248	041
249	043
250	047
251	049
252	052
253	058
254	061
255	063
256	067
257	069
258	074

259	076
260	070
261	085
262	094
263	096
264	090
265	001
266	003
267	007
268	009

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Table 5.
3-digit telephone numbers with minimum distance of 2 using the modified distance matrix of Fig. 3.

1	111
2	113
3	119
4	122
5	128
6	131
7	133
8	139
9	144
10	146
11	155
12	150
13	164
14	166
15	177
16	182
17	188
18	191
19	193
20	199
21	105
22	100
23	212
24	218
25	221
26	223
27	229
28	232
29	238
30	245
31	240
32	254
33	256
34	265
35	260
36	281
37	283
38	289
39	292
40	298
41	204
42	206
43	311
44	313
45	319
46	322
47	328
48	331
49	333
50	339
51	344
52	346
53	355
54	350
55	364
56	366
57	377
58	382
59	388
60	391
61	393
62	399
63	305
64	300
65	414
66	416
67	425
68	420
69	434
70	436
71	441
72	443
73	449
74	452
75	458
76	461
77	463
78	469
79	485

80	480
81	494
82	496
83	402
84	408
85	515
86	510
87	524
88	526
89	535
90	530
91	542
92	548
93	551
94	553
95	559
96	562
97	568
98	584
99	586
100	595
101	590
102	501
103	503
104	509
105	614
106	616
107	625
108	620
109	634
110	636
111	641
112	643
113	649
114	652
115	658
116	661
117	663
118	669
119	685
120	680
121	694
122	696
123	602

124	608
125	717
126	737
127	771
128	773
129	779
130	797
131	812
132	818
133	821
134	823
135	829
136	832
137	838
138	845
139	840
140	854
141	856
142	865
143	860
144	881
145	883
146	889
147	892
148	898
149	804
150	806
151	911
152	913
153	919
154	922
155	928
156	931
157	933
158	939
159	944
160	946
161	955
162	950
163	964
164	966
165	977
166	982
167	988

168	991
169	993
170	999
171	905
172	900
173	015
174	010
175	024
176	026
177	035
178	030
179	042
180	048
181	051
182	053
183	059
184	062
185	068
186	084
187	086
188	095
189	090
190	001
191	003
192	009

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Table 6.
4-digit telephone numbers using the modified distance matrix of Fig. 3.

1	1111
2	1113
3	1118
4	1122
5	1129
6	1131
7	1133
8	1138
9	1144
10	1146
11	1155
12	1150
13	1164
14	1166
15	1177
16	1181
–	1183
18	1188
19	1192
20	1199
21	1105
22	1100
23	1212
24	1219
25	1221
26	1223
27	1228
28	1232
29	1239
30	1245
31	1240
32	1254
33	1256
34	1265
35	1260
36	1282
37	1289
38	1291
39	1293
40	1298
41	1204
42	1206
43	1311
44	1313
45	1318
46	1322
47	1329
48	1331
49	1333
50	1338
51	1344
52	1346
53	1355
54	1350
55	1364
56	1366
57	1377
58	1381
59	1383
60	1388
61	1392
62	1399
63	1305
64	1300
65	1414
66	1416
67	1425
68	1420
69	1434
70	1436
71	1441
72	1443
73	1448
74	1452
75	1459
76	1461
77	1463
78	1468
79	1484
80	1486
81	1495
82	1490
83	1402
84	1409
85	1515
86	1510
87	1524
88	1526
89	1535
90	1530
91	1542
92	1549
93	1551
94	1553
95	1558
96	1562
97	1569
98	1585
99	1580
100	1594
101	1596
102	1501
103	1503
104	1508
105	1614
106	1616
107	1625
108	1620
109	1634
110	1636
111	1641
112	1643
113	1648
114	1652
115	1659
116	1661
117	1663
118	1668
119	1684
120	1686
121	1695
122	1690
123	1602
124	1609
125	1717
126	1737
127	1771
128	1773
129	1778
130	1787
131	1811
132	1813
133	1818
134	1822
135	1829
136	1831
137	1833
138	1838
139	1844
140	1846
141	1855
142	1850
143	1864
144	1866
145	1877
146	1881
147	1883
148	1888
149	1892
150	1899
151	1805
152	1800
153	1912
154	1919
155	1921
156	1923
157	1928
158	1932
159	1939
160	1945
161	1940
162	1954
163	1956
164	1965
165	1960
166	1982
167	1989
168	1991
169	1993
170	1998

171	1904
172	1906
173	1015
174	1010
175	1024
176	1026
177	1035
178	1030
179	1042
180	1049
181	1051
182	1053
183	1058
184	1062
185	1069
186	1085
187	1080
188	1094
189	1096
190	1001
191	1003
192	1008
193	2112
194	2119
195	2121
196	2123
197	2128
198	2132
199	2139
200	2145
201	2140
202	2154
203	2156
204	2165
205	2160
206	2182
207	2189
208	2191
209	2193
210	2198
211	2104
212	2106
213	2211
214	2213
215	2218
216	2222
217	2229
218	2231
219	2233
220	2238
221	2244
222	2246
223	2255
224	2250
225	2264
226	2266
227	2277
228	2281
229	2283
230	2288
231	2292
232	2299
233	2205
234	2200
235	2312
236	2319
237	2321
238	2323
239	2328
240	2332
241	2339
242	2345
243	2340
244	2354
245	2356
246	2365
247	2360
248	2382
249	2389
250	2391
251	2393
252	2398
253	2304
254	2306
255	2415
256	2410
257	2424
258	2426
259	2435
260	2430
261	2442
262	2449
263	2451
264	2453
265	2458
266	2462
267	2469
268	2485
269	2480
270	2494
271	2496
272	2401
273	2403
274	2408
275	2514
276	2516
277	2525
278	2520
279	2534
280	2536
281	2541
282	2543
283	2548
284	2552
285	2559
286	2561
287	2563
288	2568
289	2584
290	2586
291	2595
292	2590
293	2502
294	2509
295	2615
296	2610
297	2624
298	2626
299	2635
300	2630
301	2642
302	2649
303	2651
304	2653
305	2658
306	2662
307	2669
308	2685
309	2680
310	2694
311	2696
312	2601
313	2603
314	2608
315	2727
316	2772
317	2779
318	2797
319	2812
320	2819
321	2821
322	2823
323	2828
324	2832
325	2839
326	2845
327	2840
328	2854
329	2856
330	2865
331	2860
332	2882
333	2889
334	2891
335	2893
336	2898
337	2804
338	2806
339	2911
340	2913
341	2918
342	2922
343	2929
344	2931
345	2933
346	2938
347	2944

348	2946
349	2955
350	2950
351	2964
352	2966
353	2977
354	2981
355	2983
356	2988
357	2992
358	2999
359	2905
360	2900
361	2014
362	2016
363	2025
364	2020
365	2034
366	2036
367	2041
368	2043
369	2048
370	2052
371	2059
372	2061
373	2063
374	2068
375	2084
376	2086
377	2095
378	2090
379	2002
380	2009
381	3111
382	3113
383	3118
384	3122
385	3129
386	3131
387	3133
388	3138
389	3144
390	3146
391	3155
392	3150
393	3164
394	3166
395	3177
396	3181
397	3183
398	3188
399	3192
400	3199
401	3105
402	3100
403	3212
404	3219
405	3221
406	3223
407	3228
408	3232
409	3239
410	3245
411	3240
412	3254
413	3256
414	3265
415	3260
416	3282
417	3289
418	3291
419	3293
420	3298
421	3204
422	3206
423	3311
424	3313
425	3318
426	3322
427	3329
428	3331
429	3333
430	3338
431	3344
432	3346
433	3355
434	3350
435	3364
436	3366
437	3377
438	3381
439	3383
440	3388
441	3392
442	3399
443	3305
444	3300
445	3414
446	3416
447	3425
448	3420
449	3434
450	3436
451	3441
452	3443
453	3448
454	3452
455	3459
456	3461
457	3463
458	3468
459	3484
460	3486
461	3495
462	3490
463	3402
464	3409
465	3515
466	3510
467	3524
468	3526
469	3535
470	3530
471	3542
472	3549
473	3551
474	3553
475	3558
476	3562
477	3569
478	3585
479	3580
480	3594
481	3596
482	3501
483	3503
484	3508
485	3614
486	3616
487	3625
488	3620
489	3634
490	3636
491	3641
492	3643
493	3648
494	3652
495	3659
496	3661
497	3663
498	3668
499	3684
500	3686
501	3695
502	3690
503	3602
504	3609
505	3717
506	3737
507	3771
508	3773
509	3778
510	3787
511	3811
512	3813
513	3818
514	3822
515	3829
516	3831
517	3833
518	3838
519	3844
520	3846
521	3855

522	3850	566	3085	610	4201	654	4400
523	3864	567	3080	611	4203	655	4512
524	3866	568	3094	612	4208	656	4519
525	3877	569	3096	613	4314	657	4521
526	3881			614	4316	658	4523
527	3883	570	3001	615	4325	659	4528
528	3888	571	3003	616	4320		
529	3892	572	3008	617	4334	660	4532
		573	4114	618	4336	661	4539
530	3899	574	4116	619	4341	662	4545
531	3805	575	4125			663	4540
532	3800	576	4120	620	4343	664	4554
533	3912	577	4134	621	4348	665	4556
534	3919	578	4136	622	4352	666	4565
535	3921	579	4141	623	4359	667	4560
536	3923			624	4361	668	4582
537	3928	580	4143	625	4363	669	4589
538	3932	581	4148	626	4368		
539	3939	582	4152	627	4384	670	4591
		583	4159	628	4386	671	4593
540	3945	584	4161	629	4395	672	4598
541	3940	585	4163			673	4504
542	3954	586	4168	630	4390	674	4506
543	3956	587	4184	631	4302	675	4611
544	3965	588	4186	632	4309	676	4613
545	3960	589	4195	633	4411	677	4618
546	3982			634	4413	678	4622
547	3989	590	4190	635	4418	679	4629
548	3991	591	4102	636	4422		
549	3993	592	4109	637	4429	680	4631
		593	4215	638	4431	681	4633
550	3998	594	4210	639	4433	682	4638
551	3904	595	4224			683	4644
552	3906	596	4226	640	4438	684	4646
553	3015	597	4235	641	4444	685	4655
554	3010	598	4230	642	4446	686	4650
555	3024	599	4242	643	4455	687	4664
556	3026			644	4450	688	4666
557	3035	600	4249	645	4464	689	4677
558	3030	601	4251	646	4466		
559	3042	602	4253	647	4477	690	4681
		603	4258	648	4481	691	4683
560	3049	604	4262	649	4483	692	4688
561	3051	605	4269			693	4692
562	3053	606	4285	650	4488	694	4699
563	3058	607	4280	651	4492	695	4605
564	3062	608	4294	652	4499	696	4600
565	3069	609	4296	653	4405	697	4747

698	4767
699	4774
700	4776
701	4814
702	4816
703	4825
704	4820
705	4834
706	4836
707	4841
708	4843
709	4848
710	4852
711	4859
712	4861
713	4863
714	4868
715	4884
716	4886
717	4895
718	4890
719	4802
720	4809
721	4915
722	4910
723	4924
724	4926
725	4935
726	4930
727	4942
728	4949
729	4951
730	4953
731	4958
732	4962
733	4969
734	4985
735	4980
736	4994
737	4996
738	4901
739	4903
740	4908
741	4012
742	4019
743	4021
744	4023
745	4028
746	4032
747	4039
748	4045
749	4040
750	4054
751	4056
752	4065
753	4060
754	4082
755	4089
756	4091
757	4093
758	4098
759	4004
760	4006
761	5115
762	5110
763	5124
764	5126
765	5135
766	5130
767	5142
768	5149
769	5151
770	5153
771	5158
772	5162
773	5169
774	5185
775	5180
776	5194
777	5196
778	5101
779	5103
780	5108
781	5214
782	5216
783	5225
784	5220
785	5234
786	5236
787	5241
788	5243
789	5248
790	5252
791	5259
792	5261
793	5263
794	5268
795	5284
796	5286
797	5295
798	5290
799	5202
800	5209
801	5315
802	5310
803	5324
804	5326
805	5335
806	5330
807	5342
808	5349
809	5351
810	5353
811	5358
812	5362
813	5369
814	5385
815	5380
816	5394
817	5396
818	5301
819	5303
820	5308
821	5412
822	5419
823	5421
824	5423
825	5428
826	5432
827	5439
828	5445
829	5440
830	5454
831	5456
832	5465
833	5460
834	5482
835	5489
836	5491
837	5493
838	5498
839	5404
840	5406
841	5511
842	5513
843	5518
844	5522
845	5529
846	5531
847	5533
848	5538
849	5544
850	5546
851	5555
852	5550
853	5564
854	5566
855	5577
856	5581
857	5583
858	5588
859	5592
860	5599
861	5505
862	5500
863	5612
864	5619
865	5621
866	5623
867	5628
868	5632
869	5639
870	5645
871	5640

872	5654	916	5952	960	6161	1004	6386
873	5656	917	5959	961	6163	1005	6395
874	5665	918	5961	962	6168	1006	6390
875	5660	919	5963	963	6184	1007	6302
876	5682			964	6186	1008	6309
877	5689	920	5968	965	6195	1009	6411
878	5691	921	5984	966	6190		
879	5693	922	5986	967	6102	1010	6413
		923	5995	968	6109	1011	6418
880	5698	924	5990	969	6215	1012	6422
881	5604	925	5902			1013	6429
882	5606	926	5909	970	6210	1014	6431
883	5757	927	5011	971	6224	1015	6433
884	5775	928	5013	972	6226	1016	6438
885	5770	929	5018	973	6235	1017	6444
886	5707			974	6230	1018	6446
887	5815	930	5022	975	6242	1019	6455
888	5810	931	5029	976	6249		
889	5824	932	5031	977	6251	1020	6450
		933	5033	978	6253	1021	6464
890	5826	934	5038	979	6258	1022	6466
891	5835	935	5044			1023	6477
892	5830	936	5046	980	6262	1024	6481
893	5842	937	5055	981	6269	1025	6483
894	5849	938	5050	982	6285	1026	6488
895	5851	939	5064	983	6280	1027	6492
896	5853			984	6294	1028	6499
897	5858	940	5066	985	6296	1029	6405
898	5862	941	5077	986	6201		
899	5869	942	5081	987	6203	1030	6400
		943	5083	988	6208	1031	6512
900	5885	944	5088	989	6314	1032	6519
901	5880	945	5092			1033	6521
902	5894	946	5099	990	6316	1034	6523
903	5896	947	5005	991	6325	1035	6528
904	5801	948	5000	992	6320	1036	6532
905	5803	949	6114	993	6334	1037	6539
906	5808			994	6336	1038	6545
907	5914	950	6116	995	6341	1039	6540
908	5916	951	6125	996	6343		
909	5925	952	6120	997	6348	1040	6554
		953	6134	998	6352	1041	6556
910	5920	954	6136	999	6359	1042	6565
911	5934	955	6141			1043	6560
912	5936	956	6143	1000	6361	1044	6582
913	5941	957	6148	1001	6363	1045	6589
914	5943	958	6152	1002	6368	1046	6591
915	5948	959	6159	1003	6384	1047	6593

1048	6598
1049	6504
1050	6506
1051	6611
1052	6613
1053	6618
1054	6622
1055	6629
1056	6631
1057	6633
1058	6638
1059	6644
1060	6646
1061	6655
1062	6650
1063	6664
1064	6666
1065	6677
1066	6681
1067	6683
1068	6688
1069	6692
1070	6699
1071	6605
1072	6600
1073	6747
1074	6767
1075	6774
1076	6776
1077	6814
1078	6816
1079	6825
1080	6820
1081	6834
1082	6836
1083	6841
1084	6843
1085	6848
1086	6852
1087	6859
1088	6861
1089	6863
1090	6868
1091	6884
1092	6886
1093	6895
1094	6890
1095	6802
1096	6809
1097	6915
1098	6910
1099	6924
1100	6926
1101	6935
1102	6930
1103	6942
1104	6949
1105	6951
1106	6953
1107	6958
1108	6962
1109	6969
1110	6985
1111	6980
1112	6994
1113	6996
1114	6901
1115	6903
1116	6908
1117	6012
1118	6019
1119	6021
1120	6023
1121	6028
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