

DIGITAL RADIO-TELEPHONY PROCESS AND APPARATUS, PARTICULARLY FOR CELLULAR RADIOTELEPHONE FOR COMMUNICATION WITH
5 MOBILES

The invention generally relates to processes and apparatuses for digital radio-telephone communication whose implementation requires broadcast by a stationary
10 infrastructure, periodically and at high rate, towards transmitter-receiver stations, serial numbers of frequencies which constitute any sub-set, having a cardinal number or range which is at most equal to a predetermined value n , of a set of predetermined frequencies having a
15 cardinal number N .

The invention is particularly suitable for use in radio-telephone systems (the term "radio-telephone" being construed broadly and as relating to data transmission as well as to speech transmission) known as "cellular",
20 whose standards are being prepared by the Conférence Européenne des Administrations des Postes et Télécommunications. A description of the general features of such systems may be found in the paper "Le système cellulaire numérique européen de communication avec les mobiles", by
25 B. GHILLEBAERT et al, in Echo des Recherches, n° 131, first quarter 1988. Those aspects of digital cellular radio-telephone particularly concerned by the present invention are for instance described in recommendation GSM 04.08 "Mobile radio interface layer 3 specification",
30 published in March 1990 by the special group "Public Mobile Systems of Radio-telecommunication" of CEPT.

In a cellular radio-telephone system as hereinbefore defined, the infrastructure should transmit, on broadcasting channels, two list of frequencies which are repeated at regular intervals. A first list is that of frequencies on which, in a given cellule or zone, the mobile
35 station is to operate with frequency hopping modulation (see US-A-4 850 036).

A second list is that of the frequencies of the broadcasting channels that the station should monitor, in stand-by or waiting condition, for cellule selection, and in connected condition, for measurement and comparison needs.

As an indication, it is presently envisioned that the list of frequencies to be monitored will be communicated at a rate of about one per second. It is also envisioned to communicate, to a mobile transmitter-receiver station, in response to a request for allocation by the latter, the serial numbers of the frequencies which are dedicated to it for transmission, such frequencies constituting a sub-set, having a cardinal number at most equal to $n = 16$, of a set of $N = 2^{10} = 1\ 024$ frequencies.

The transmission mode should be such as to authorize adoption of any one of the possible sub-sets, which excludes the process which would consist, in the case of a limited number of sub-sets, to dedicate an identification number which would be alone transmitted to each. Individual transmission of the serial number of each frequency of the selected sub-set would require, in the most unfavorable case, to encode 16 serial numbers, each on 10 bits.

It is a general object of the present invention to reduce the volume of binary data necessary for transmitting the serial numbers of the frequencies to be used, the serial numbers being possibly considered as elements belonging to a set $0, \dots, N-1$. It is a more particular object to provide a simple solution to the problem when the number of elements N is equal or slightly higher than a whole power of 2, i.e. when N is equal or slightly higher than 2^k (k being an integer).

For that purpose, the invention particularly provides a process of digital radio-telephone communication, including the steps of : broadcasting, from a stationary infrastructure toward mobile transmitter-receiver

stations, the serial numbers of working frequencies which constitute any sub-set, having a cardinal number at most equal to a predetermined value n , of a set of predetermined frequencies of cardinal N ; identifying, in each receiving station, frequencies of the sub-set from the serial numbers and causing the station to operate on the identified frequencies,

characterized in that, for broadcasting the serial numbers of frequencies belonging to a set of cardinal number 2^k-1 , the number V of the frequency for which half of the remaining frequencies has a lower serial number and half of the remaining frequencies have a serial number higher than V is identified; the serial number of the selected frequency is identified on k bits; the serial numbers of the two divided groups of frequencies are renumbered; determination of the serial number of the frequency is repeated on each group and the two partition frequencies are defined on $k-1$ bits; the operations of renumbering, determination and definition are repeated until the serial numbers to be transmitted are exhausted; all serial numbers of the partition frequencies are transmitted according to a predetermined sequence known at the transmitter-receiver station, and the working frequencies are determined from the serial numbers, in the station.

The term "lower" serial number and "higher" serial number should not construed as indicating a relation in natural order, but rather as indicating that the serial numbers belong to that half of the original set which follows the value or which precedes the value, respectively, in a circular arrangement. Thus, the serial number V of the partition frequency may be considered as delimiting, in the interval $[0, 2^k-2]$, two groups including the $2^{k-1}-1$ serial numbers respectively preceding and following V in a circular disposition of said interval, V being chosen such that $L(n/2)$ serial numbers of frequencies of the sub-set belong to one of the two groups, $L(.)$ designating the integer part.

The process is applicable for any value of N. However, it is of particular interest when N may be written as 2^k-1 since that removes the need for mixed radix arithmetics and consequently simplifies computation by substituting
5 mere shifts to multiplication or division operations.

That particular case is frequently encountered.

Frequently the number of possible frequencies, i.e. the number N of elements in the set may be written as 2^k , due to reasons related to the use of binary mode transmission. Then the number of elements may easily be reduced from
10 2^k to 2^k-1 by identifying one of the frequencies, arbitrarily selected in the set, with a single bit which is 0 or 1 depending on whether the respective frequency is present or not.

15 When the number N of elements in the set is slightly higher than a whole power 2^k , another approach consists in using the above-defined process for 2^k-1 elements (the first or the last elements of the list for instance) and identifying the serial numbers of the other elements by mapping.

20 When the number of the elements in the set may be written as 2^k-1 and when the cardinal number of the sub-set is optimum, then the process according to the invention makes it possible to carry out transmission with a total number of bits which is close to the theoretical minimum.
25 The gain is not as high as in the particular case of cellular digital radio-telephone as provided by the standard, but it is sufficient for authorizing transmission of all serial numbers of the 16 frequencies (maximum number) which are necessary, among 1 024, with 128 bits, i.e. 2^4
30 bytes, even when 2 bits should be reserved as header. The mobile stations used comprise means for matching a respective predetermined frequency with each of the serial numbers in the received set and a decoder capable to provide the actual serial number, in clear, to said means, from a
35 message resulting from the above-defined process.

The means may consist of a processor, which is

anyway necessary in the movable station for fulfilling other functions, when the different possible frequencies can be deduced from one another by an algorithm including the serial number. Such means may have other constructions and for instance may use a matching table stored in a programmable read only memory.

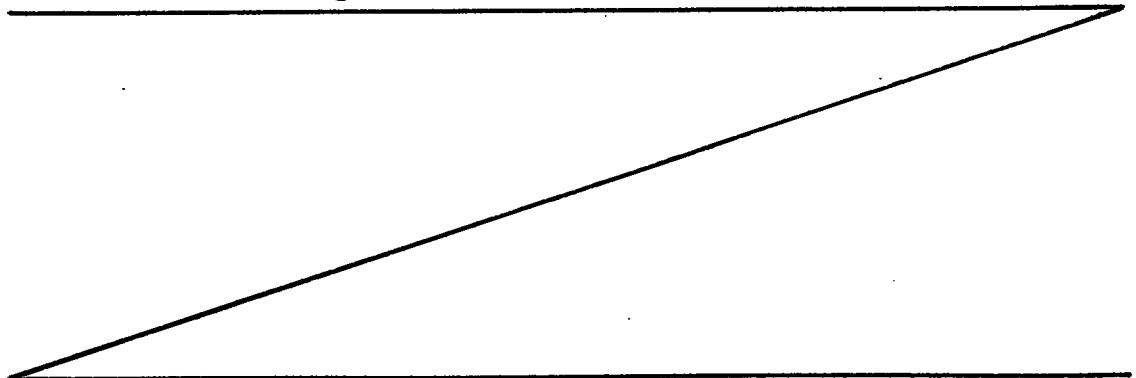
The invention will be better understood from the following description of a particular embodiment and of modified embodiments. The description refers to the accompanying drawings, wherein:

- Figures 1 and 2 are "loop" sketches indicating how the first and second nodes are selected;
- Figure 3 is a representation of a possible broadcasting format.
- Figure 4 is a general block diagram.

The description will first be given of the encoding process (and of the corresponding decoding process) making it possible to reduce the number of bits necessary for transmitting the serial numbers of n frequencies belonging to a set of cardinal number N , before the encoding and decoding mode for $N = 2^k - 1$ and a corresponding program are given.

Encoding is equivalent to a process of identification of elements, whose minimum number is n , belonging to a sub-set by a partition method including a tree selection approach, the code of an element depending on previously selected elements.

By selecting a "parent" element, a left group and a right group are formed and in each group a "child" is selected according to a selection which is the same as for



the parent: arbitrarily, the second child may be considered as being the left-hand child. It is smaller than the parent and may be encoded with a number of bits which is lower by one unit. The right-hand child is greater than the parent but can be reduced to a lower value by a subtraction operation, thereby making it possible to encode it with the same number of bits as the left-hand one.

The first step of the partition process is schematically illustrated in Figure 1, on which seven elements constituting a sub-set to be identified and to be encoded are illustrated, the seven elements being among R elements $0, 1, \dots, R-1$. A node will be defined as the value V which separates two groups :

- the right-hand group, from $V + 1$ to $V + L[(R-1)/2]$ (the notation $L(.)$ is used herein to designate the integer part);

- the left-hand group, from the preceding value, increased by one, to $V-1$.

Referring to Figure 1, the two groups may be defined on a loop, value $R-1$ being followed with the value 0 .

It can be demonstrated that it is always possible to find an element whose value V is such that there are exactly $L(n/2)$ values in the left-hand group. That convention will generally be used for defining V . Another convention would however also be possible.

After the first partitioning has been carried out, a first and second child, each in one of the groups, are determined. Arbitrarily, it will be assumed in the following that the second child is the left-hand one, the third child is that at right.

Referring to Figure 2, first the elements of the left-hand group are renumbered beginning from $V + L[(R-1)/2]$. Similarly, the elements of the right-hand group are renumbered from V .

The process is then carried out again and makes it

possible to determine the new child V1, using the same criterion as above.

At each partition, it is possible to encode the children with a number of bits which is lower by one unit than that necessary for the parent : if initially k bits are necessary, $k-1$ bits are sufficient for the two immediate children, $k-2$ bits for the four following children, etc.

Selection of the nodes may be carried out by a simple, however slow, process consisting in carrying out a test on each element in turn; however fast, more complex, algorithms can also be used.

It can be seen that the values assigned to all nodes have a number of bits which is independent from the values to be encoded, i.e. from the serial numbers, and depend on predetermined conventions only (stored on emission and reception) and of the cardinal number of the set.

As indicated above, particularly favorable results are obtained when the cardinal number of the initial set is equal to 2^k-1 , k being any integer. Then k bits are just sufficient and necessary for encoding the first node while $k-1$, then $k-2$ bits, etc. are necessary for the nodes of the following generations. The structure is then wholly binary, and the complexity resulting from encoding and decoding with a mixed radix is avoided.

Decoding operations in the movable station, where the selected conventions are stored, are reverse from those which have just been described. A processor first identifies the first node, whose serial number is directly given in binary code. Then it carries out the numerations required for reconstructing the first two children. Then the processor, using a predetermined algorithm which associates the frequency values with their serial numbers, delivers to the emitter-receiver portion of the station the values of the frequencies which correspond to

the channels to be monitored and/or to the channel on which transmission should be carried out for communication with the infrastructure.

- 5 The performances which are obtained immediately appear when the cardinal number of the set is equal to 2^k-1 . In that case, which is typical of the situation for cellular radio-telephone, where $N = 2^{10}-1 = 1\ 023$ and where $n = 16$, :

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- 10 bits are necessary for the first node,
 - 9 bits are necessary for each of the following two nodes,
 - 8 bits are necessary for each of the following
- 15 four nodes,

and similarly until six bits are necessary for the single node of the fourth generation. The total number is consequently 122 bits.

- 20 As indicated above, 1 supplemental bit is sufficient for increasing the total number of frequencies among which selection can be carried out to 1 024.

For any value N of the cardinal number of the set, the necessary number of bits is :

25

$$\frac{N \log n}{\log 2} = \sum_{i=1}^N \frac{\log i}{\log 2}$$

where $[x]$ designates the integer part of x .

30

The gain on the number of bits, as compared to an encoding mode consisting in giving all values constituting the sub-set as a number having the maximum number of bits which may be necessary, depends on the number of the elements. As an example, some values are given thereunder:

35

n	1	2	3 ...	15...	23...	30
gain						
5 (bits)	0	1	2	34	66	94

and the following table gives the number of bits which is necessary in a number of typical situations :

10

	Range of the set	Number of elements in the sub-set	Number of bits required
15	1 023 - } 2 ¹⁰ -1	14 15 16	109 116 122
20	511 - } 2 ⁹ -1	20 22 25	106 114 126

As an example, there will now be given a sequence of partiting operations necessary for sending, to a mobile station, a particular sub-set of elements, consisting of sixteen serial numbers belonging to a set of 2¹⁰ serial numbers of frequencies having the values $f_0, \dots, f_{1023}$. It will be assumed that the sub-set consists of frequencies whose serial numbers are : 12,70,121,190,250,320,401,475, 520,574,634,700,764,830,905,980.

For decreasing the cardinal number or range of the set from 1 024 to 1 023, one frequency, arbitrarily selected, is identified with one bit. Presence or absence of the frequency in the sub-set is indicated by sending a single bit. That frequency has to be stored in the mobile station. It is for instance f_0 or $f_{1\ 023}$. Consequently, the maximum number of elements to be transmitted is sixteen and they consist of sixteen numbers between 1 and 1 023.

A first node then consists of that element $V = 520$ whose "opposed" value is $[520 + (2^9 - 1)] \text{ modulo } (2^{10} - 1)$ i.e. 8: it is seen that there are eight elements between 9 and 519 (belonging to the left-hand group) 12, 70, 121, 190-250, 320, 401, 475) and seven elements between 521 and 8, as indicated by the following table.

TABLE I

10			520	
			(opposed = 8)	
	12	(3)		574
	70	(61)		634
15	121	(112)		700
	190	(181)		764
	250	(241)		830
	320	(311)		905
	401	(392)		980
20	475	(466)		

Arbitrarily, in the case (which is that of the above example) where the number of elements to be parted is even, the node is so selected that there is one element more in the left-hand group. The contrary possibility could be used; It is only essential that it is stored in the station.

The first node is encoded with 10 bits, even when a lower number of bits would be sufficient.

The second node consists of the child of the first node, arbitrarily in the left-hand group, renumbered starting from nine, i.e. from the opposite of 520. Renumbering is indicated between parentheses in the above table. It is seen that value 112 (corresponding to the element which was initially numbered 121) separates the group into two sub-groups of four and three elements respectively.

The third node consists of the child of the first in the right-hand group. Then renumbering is carried out

from 521, again from 1 to $2^9 - 1 = 511$ which gives seven elements numbered 53, 113, 179, 243, 309, 384 and 459.

Value 53 separates that group into two sub-groups each of three elements, comprised between 54 and the value 309 opposed to 53.

In the new numbering, the second and third nodes can be encoded with nine bits, since their values are lower than 512.

It is proceeded with a method to obtain the following nodes. Arbitrarily, it will be considered here that each even node $2m$ is the left-hand child of node m while the odd node $2m+1$ is the right-hand child of node m .

The successive nodes are then identified by the values of table II :

TABLE II

	Node	Value	Number of bits
20	1	520	10
	2	112	9
	3	53	
25	4	146	8
	5	68	
	6	0	
	7	59	
30	8	5	7
	9	57	
	10	2	
	11	59	
	12	22	
	13	74	
	14	2	
35	15	65	
	16	10	6

Mixed radix encoding is very simple in that particular case since it is such that there is an exact correspondence between values and words having a decreasing
 5 number of bits.

The above values, plus one, are then encoded in the appropriate order, then transmitted as 10 bits, then 9 bits, then 8 bits, then 7 bits and, last, (for the single elements for a sub-set of 16 elements) 6 bits:

10 Conversely, decoding is very simple. For instance, for the second node, the original value is:

$$(520 + 511 + 113) \bmod 1\ 023 = 121$$

15 while for node 11, the original value is :

$$\{520 + 511 + [113 + (69 + 60) \bmod 255] \bmod 511\} \bmod 1\ 023$$

i.e. 250.

20 In the above formula ($n \bmod p$) designates the integer r for which there exists a number d such as $1 \leq r \leq p$ and $n = dp + r$.

That formula is used for differenciating from modulo, which is such that $0 \leq r \leq p-1$.

25 Encoding and decoding can easily be carried out by software. A decoding program corresponding to a specific situation and language will now be given, as an example only.

30 w_i will be used to designate the i th word appearing in the field. When w_i is equal to zero, the description of the sub-set is ended and all following bits in the field are set to zero. When the format of the broadcast message is of the type illustrated in Figure 3, the serial numbers of the sub-set are computed as follows.

35 Bit f_0 indicates whether frequency F_0 is present or not : if present, it is immediately identified.

The serial numbers of the 16 frequencies F_1 to F_{16}

or F_0 to F_{15} (the number possibly being lower than 16) are given by:

$$\begin{aligned}
 5 \quad & F_1 = W_1 \text{ smod } 1023 \\
 & F_2 = (W_1 - 512 + W_2) \text{ smod } 1023 \\
 & F_3 = (W_1 + W_3) \text{ smod } 1023 \\
 & F_4 = (W_1 - 512 + (W_2 - 256 + W_4) \text{ smod } 511) \text{ smod } 1023 \\
 & F_5 = (W_1 + (W_3 - 256 + W_5) \text{ smod } 511) \text{ smod } 1023 \\
 & F_6 = (W_1 - 512 + (W_2 + W_6) \text{ smod } 511) \text{ smod } 1023 \\
 & F_7 = (W_1 + (W_3 + W_7) \text{ smod } 511) \text{ smod } 1023 \\
 10 \quad & F_8 = (W_1 - 512 + (W_2 - 256 + (W_4 - 128 + W_8) \text{ smod } 255) \\
 & \quad \text{smod } 511) \text{ smod } 1023 \\
 & F_9 = (W_1 + (W_3 - 256 + (W_5 - 128 + W_9) \text{ smod } 255) \\
 & \quad \text{smod } 511) \text{ smod } 1023 \\
 & F_{10} = (W_1 - 512 + (W_2 + (W_6 - 128 + W_{10}) \text{ smod } 255) \\
 & \quad \text{smod } 511) \text{ smod } 1023 \\
 & F_{11} = (W_1 + (W_3 + (W_7 - 128 + W_{11}) \text{ smod } 255) \\
 & \quad \text{smod } 511) \text{ smod } 1023 \\
 15 \quad & F_{12} = (W_1 - 512 + (W_2 - 256 + (W_4 + W_{12}) \text{ smod } 255) \\
 & \quad \text{smod } 511) \text{ smod } 1023 \\
 & F_{13} = (W_1 + (W_3 - 256 + (W_5 + W_{13}) \text{ smod } 255) \\
 & \quad \text{smod } 511) \text{ smod } 1023 \\
 & F_{14} = (W_1 - 512 + (W_2 + (W_6 + W_{14}) \text{ smod } 255) \\
 & \quad \text{smod } 511) \text{ smod } 1023 \\
 20 \quad & F_{15} = (W_1 + (W_3 + (W_7 + W_{15}) \text{ smod } 255) \\
 & \quad \text{smod } 511) \text{ smod } 1023 \\
 & F_{16} = (W_1 - 512 + (W_2 - 256 + (W_4 - 128 + (W_6 - 64 + W_{16}) \\
 & \quad \text{smod } 127) \text{ smod } 255) \text{ smod } 511) \text{ smod } 1023
 \end{aligned}$$

25 Each $w(i)$, in bytes 2 to 17, constitutes the coded value of a non-negative integer in binary format. If $W(i)$ is zero for a value 1, then words $W(1+1)$ to $W(16)$ are also equal to zero. The adopted symbols are as follows :

30 - + indicates addition of natural integers,
 - * indicates multiplication of natural integers,
 - $n \bmod m$ indicates the remainder of the euclidian division of n by m , i.e. $0 \leq (n \bmod m) \leq m-1$, which implies that there exists a value p such as :

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$$p = k*m + (n \bmod m).$$

The program may be as follows, using ADA language. The declarative parts have been skipped since they are obvious :

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5      INDEX := K;
      J := GREATEST_POWER_OF_2_LESSER_OR_EQUAL_TO(INDEX);
      N := W(INDEX);
      while INDEX > 1 loop
        PARENT_INDEX := J/2 + (INDEX-J) mod (J/2);
        if 2*INDEX < 3*J then          -- left child
10         N := (N + W(PARENT_INDEX) - 1024/J - 1) mod (2048/J - 1)
            + 1;
        else                            -- right child
          N := (N + W(PARENT_INDEX) - 1) mod (2048/J - 1) + 1;
        end if;
        INDEX := PARENT_INDEX;
        J := J/2;
15      end loop;
      F(K) := N;

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20 Encoding is carried out by a program which reflects the decoding process; consequently the encoding program may be directly deducted from the decoding process which has just been given.

25 Numerous modifications of the invention are possible and only some of them will now be briefly mentioned.

30 A first modification consists in simplifying encoding by not fully using the mixed radix base arithmetic concept, but instead by encoding a given value with an integral number of bits. For instance it is then possible to use 9 bits for encoding a value comprised between 0 and 350. That simplifies encoding and decoding since the divisions and multiplications are replaced with binary shifts. The cost, as regards the number of bits, is about 1/2 bit per encoded value ; for the above example, the number of bits which is required is then increased by an amount which is zero when N is equal to 2^k-1 , whatever k if it is an integer.

Still another process making it possible simultaneously to preserve purely binary coding and performances when the range or cardinal number of the set is only slightly higher than 2^k-1 consists in using a mapping procedure for the values beyond 2^k-1 .

Another modification makes it possible to adapt the above described encoding-decoding process to the situation where the possible sub-sets represent only a predetermined portion of all possible sub-sets of the set of N elements.

The modification implies to give, at the beginning of the format, an indication of the range or of the portion of the set within which all elements of the sub-sets to be encoded are found. Several approaches are possible.

- A first solution consists in giving the lowest value and the highest value of the domain in which the elements are to be found. That consumes $2 \log N - 1$ bits. The remaining available bits are used for encoding the values. The relationship between the value k such that all sub-sets having at most k values can be coded and the domain (maximum value - minimum value) is as follows, assuming a maximum number of 124 bits :

Domain	max.number of elements
1023	15
511	17
255	21

Obviously, it is more advantageous to use mapping coding if the domain has 106 elements or more.

- A second solution consists in firstly encoding the lowest value (with ten bits in the above example), then the range (highest value minus lowest value), for instance with three bits. The relation then becomes :

	Domain	max. number of elements
5	1023	15
	511	18
	255	22
	127	29

10 For a domain having less than 112 elements, it is preferable to encode on a mapping basis.

It is seen that there is neither a gain, nor a loss for extended domains, but there is an advantage for domains having less than 150 elements.

15 Last, still another modification consists in not giving the exact first value, but rather indicating only a first bound among a plurality of bounds, indicating that the domain will not be lower than the bound. The bound may for instance be selected among 21 different values in the above-identified case.

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CLAIMS

1. Process for digital radio-telephone communication
5 between an infrastructure and mobile stations, including the
steps of: broadcasting, from the stationary infrastructure
toward the mobile transmitter-receiver stations, the serial
numbers of working frequencies which constitute any sub-set,
having a cardinal number at most equal to a predetermined
10 value n , of a set of predetermined frequencies having a
cardinal number N ; identifying, in each receiving station,
the working frequencies of the sub-set by deriving them from
the serial numbers; and causing the station to operate on
the identified frequencies,
15 characterized in that, for broadcasting, the serial
numbers of frequencies belonging to a set of cardinal
numbers 2^k-1 , k being an integer, the serial number V of a
partition frequency belonging to said sub-set which deli-
mits, in the interval $[0, 2^k-2]$, two groups including the
20 2^k-1 serial numbers respectively preceding and following V
in a circular arrangement of said interval is determined, V
being chosen such that $L(n/2)$ serial numbers of frequencies
of said sub-set belong to one of the two groups, $L(.)$
designating the integer part; the serial number of the
25 retained partition frequency is identified on k bits; the
serial numbers in the two delimited groups are renumbered;
determination of the serial number of a partition frequency
is repeated on each group and the two partition frequencies
are defined on $k-1$ bits; the operations of renumbering,
30 determination and definition are repeated until the serial
numbers to be transmitted are exhausted; all serial numbers
of the partition frequencies are transmitted according to a
predetermined sequence known at the transmitter-receiver
station; and the working frequencies are determined from the
35 serial numbers, in the station.

2. Process according to claim 1, characterized in



that it is used for broadcasting the serial numbers of frequencies included in a set of cardinal number 2^k-1 while transmitting the possible additional serial numbers in a different way.

5 3. Process according to claim 2, characterized in that the number N of the elements is decreased from 2^k to 2^k-1 by identifying one of the frequencies, arbitrarily selected within the set, with a single bit which is set to zero or to one depending on whether the relevant frequency
10 is present or not in said sub-set.

 4. Process according to claim 2, characterized in that, the number N of elements being only slightly higher than 2^k , it is used for encoding 2^k-1 elements (for instance, the first elements or the last elements of the list) and the
15 serial numbers of the other elements are identified by mapping.

 5. Mobile radio-telephone station for a cellular digital radio-telephone system using frequency hopping modulation comprising transmitter-receiver means over a
20 plurality of frequencies defined by serial numbers and constituting a sub-set of frequencies having a cardinal number at most equal to n, included in a set of frequencies whose serial numbers constitute a set having a cardinal number N, means for monitoring a broadcasting channel,
25 frequency generating means for assigning a predetermined frequency to each of the serial numbers of the set, characterized in that it further comprises a decoder for providing the actual serial number, in clear, to said means from a message containing the list of numbers encoded by the
30 process according to claim 1.

 6. Station according to claim 5, characterized in that the generating means comprise a processor which generates the different possible frequencies through an algorithm involving the serial number.