

METHOD AND DEVICE FOR ALLOCATING CHANNELS

The invention notably relates to a method and device allowing channels for sharing data between a plurality of users to be optimally allocated. The invention is applicable when the users are radio equipment desiring to exchange their positions, for example in a communication system. The invention is used when it is desired to recurrently share information between users while minimizing the refresh period corresponding to the plurality of successive sessions required to ensure that each user U_i is able to communicate at least once with each of the other users U_j .

During what is called a refresh period, which must be as small as possible, each user must be able to communicate, to all the other users, a personal datum, for example its current position. When the environment of the users is not especially dense, and when two users are in radio range, the simplest and most effective deterministic solution consists in each transmitting its position in turn. It is thus possible to envision closely spaced emissions that have a shorter refresh period, but which would cause jamming in a dense environment. The total transmission period is equal to the number of users multiplied by the duration of one time slot or transmission slot. The expression "in radio range" is understood to mean that a user is visible in the radio sense and that it can exchange information with another user.

In a dense user context, many users are in radio range of one another. It is then advantageous to envision co-operative relaying in which the users transmit, in addition to their position, the position of any users detected beforehand, i.e. any users with which they have been able to exchange data. In the context of co-operative relaying, successive transmission over a single logic channel is of little or no interest because the users, if they are in radio range, receive the same information simultaneously. They therefore have little or no useful information to transmit in addition to their position.

The following description will make use of the terms defined below. The N users emit and listen according to a periodic scheme. The period of this scheme corresponds to one frame or one period. The users emit over C logic channels and listen to the other users using the same logic channel. The users of a given logic channel successively emit over the logic channel. The allocations of the logic channels to the users are modified several times over the duration of the frame. The period during which the users remain assigned to the same logic channel is called a session. The various sessions making up the frame may be of different durations. A refresh period is defined as the sum total of the durations of the t successive sessions required to ensure that each user U_i is able to communicate at least once to each of the other users U_j its personal datum.

For any one particular user-channel (N, C) doublet, it is possible to seek, using a solver, a specific solution that best satisfies the constraint of minimization of the refresh period. It will be noted that small variations in the parameters N, C, n (n is about equal to N/C) may considerably increase the minimum period found. One of the objectives is for the observed achieved minimum to remain systematically close to the theoretical "combinatory" limit t^* , i.e. the smallest t such that:

$$t C n(n-1)/2 \geq N(N-1)/2.$$

i.e. $t^* \geq N^2/(n^2 C).$

One known method consists in using a pseudo-random assignment rule (i.e. in picking partitions of groups of n users "at random" in each session). This method has the drawback of connecting the same subscribers a number of times in the successive sessions forming the period, and may in contrast leave some remaining pairs of subscribers without connection, it then being necessary to process this remnant with one or more particular additional sessions. In addition, this solution never gets close to the desired optimal.

For a session, the number of pairs $\{i,j\}$ of connected users (i.e. U_i, U_j assigned to the same channel) is: $C n(n-1)/2$.

In a session, a pair is therefore connected with the probability:

$$p = C n(n-1)/2 / (N(N-1)/2) \sim C (n/N)^2.$$

After t sessions, the number of pairs still not connected is therefore about:

$$(1-p)^t N(N-1)/2 \sim (1 - C (n/N)^2)^t N^2/2.$$

- 5 The order of magnitude of t required for the number of pairs still not connected after t sessions to be close to 0 is therefore such that:

$$t \ln((1 - C (n/N)^2) + \ln(N^2/2)) = \ln(1).$$

Namely, assuming that $\varepsilon = C (n/N)^2 \ll 1$:

$$-t C (n/N)^2 + \ln(N^2/2) = 0$$

10 $t \gtrsim \ln(N^2/2) / t^*.$

With respect to the minimum limit t^* , the multiplicative factor " $\ln(N^2/2)$ " (typical of the conventional "coupon collector's problem") of the refresh period of the "pseudo-random" solution is not negligible.

- One of the objectives of the invention is to provide a new approach allowing
 15 transmission logic channels to be optimally allocated, by making it so that any two users belonging to a network see each other at least once in the period of the frame and so that, over the duration of a frame, any two users are assigned at least once to the same logic channel during a given session.

- The invention relates to a method for allocating communication
 20 logic channels to N users in a network, comprising at least the following steps:

- a) defining a first allocation set composed of the following triplets (channel number, slot number, user attributed to a channel for a given slot) representing the allocation of C communication channels, to the N users, in a
 25 first time session composed of a plurality of time slots, with the number C of communication channels equal to the square root of the number of users N and C equal to the cardinal of a finite field,
- b) generating, from the first channel allocation set, C other matrices, each matrix describing the allocation of the users to the communication channels
 30 during a session, said C allocation matrices being generated using a function configured so that each user is listening to each of the other users at least

once during the frame containing the $C+1$ sessions, the communication actually taking place if the users are in communication range.

According to one variant embodiment, the allocation set takes the form of a matrix and an allocation matrix is generated from the first allocation
5 matrix by scanning the columns and rows of the matrix using straight lines of variable slopes.

In the case where the relationship $C = \sqrt{N}$ is not satisfied, a number of inactive users is for example chosen and $N' > N$ active or inactive users, with $C = \sqrt{N'}$, are treated and the position of the inactive users is
10 optimized to minimize the size of the frame.

In the case where the number of available channels is lower than the square root of the number of users, the users are grouped together into subgroups of at most k users with $(k-1) \cdot q^2 < N \leq k \cdot q^2$ where q is the number of available channels.

15 A group of users may be composed of a plurality of subsets of users, such as pairs, triplets and/or single users.

The invention relates to a method for sharing data between a plurality of users, comprising the step of allocating communication channels according to the invention and a step in which the users exchange their
20 positions and the positions of their neighbours in radio range.

The users may be radio equipment.

The invention also relates to a device for allocating communication channels to a plurality of users U_i in a network, characterized in that it comprises a device configured to execute the steps of the method according
25 to the invention, and means for storing the set including the allocation of the channels C as a function of a slot S and for a user.

According to one variant embodiment, each user is equipped with a processor configured to execute the steps of the method according to the invention.

30 A user may be a piece of radio equipment in an ad-hoc communication network.

Other features and advantages of the present invention will become more clearly apparent on reading the description of example embodiments with reference to the figures, which show:

- Figure 1, an example of an architecture of a communication network including a plurality of users,
- Figure 2, a schematic of the construction of channel allocation matrices for the duration of a frame,
- Figure 3 and Figure 4, two concrete examples of matrices.

In order to better understand the method according to the invention, the following description is given for a network comprising a plurality of users that are radio equipment and that will seek to exchange their positions, their position possibly varying over time.

Figure 1 schematically shows a network comprising a plurality of pieces of radio equipment. Each radio equipment 10i is equipped with an emitter/receiver device 11i, with a processor 12i, and with a database 13i that stores the channel allocation matrices for a user and for a transmission slot, the matrices being defined as will be detailed below. The matrices will be used to determine the emission/reception times and the emission/reception channels of each piece of radio equipment. Figure 1 also shows a device 30 comprising a processor 31 configured to execute the steps of the method according to the invention, and a database 32 in which parameters for configuring the network are stored. The device 30 will generate channel allocation matrices that will be loaded into each piece of radio equipment using techniques known to those skilled in the art, and that will allow channels to be optimally allocated to the pieces of radio equipment.

Without departing from the scope of the invention, it is possible to imagine generating these matrices during the operation of the system, while taking into account for example possible changes in the communication channels to be allocated and/or the fact that the number of users is liable to vary over time. In this case, the radio equipment are configured to perform

the calculations. The users change emission/reception frame simultaneously because the frame is global.

The matrices contain the following information: the reference of a radio equipment, or of a set of pieces of radio equipment, and the channel
 5 attributed to a radio equipment or a set for a given slot of a session. This information could be grouped together in a format other than that of a matrix, without departing from the scope of the invention.

A channel allocation matrix comprises C rows representing the transmission channels, and S columns corresponding to the number of time
 10 slots in a session. One element of a matrix corresponds to the identifier of a user or of a group of users connected to a channel C_i for a given slot S_i .

On start-up, to generate the allocation matrices, the following parameters are available:

- The number of user of radio equipment: N ,
- 15 • The number of communication channels: C .

The parameter n representing the users subscribed to a channel may change from one session to the next, during the period. It may also vary depending on the logic channel, for a given session. In practice, the highest possible value will be chosen for n , i.e. a value of about N/C , because a given user
 20 can be assigned to only a single logic channel. If N is not a multiple of C , the parameter n varies depending on the channel in question. For the sake of simplicity, the parameter n is not indexed by the channel number. Considering all the channels, the duration of the session is dependent on the highest value of n .

25 During an elementary session, i.e. a session of communication and exchange of data,

- A user emits over or listens to only its assigned channel,
- Users connected to the same channel during the session share their personal data, for example via a conventional TDMA (Time Division
 30 Multiple Access) radio procedure,

- The C channels are used in parallel by subgroups of n separate subscribers.

In each session, the method specifically reselects the subgroups assigned to each channel.

5 The refresh period is the sum total of the durations of the t successive sessions required to ensure that each user U_i is able to communicate at least once to each of the other users U_j its personal data. In other words the time required for the following condition to be met: for each pair of users $\{U_i, U_j\}$, U_i and U_j are connected at least once over the same
10 channel during one session of the period.

The assignment of each user to each channel is done session by session.

During a session:

- The C channels are used in parallel,
- 15 - One channel allows at most n subscribers among the N to be connected,
- The subscribers "connected" over a given channel during the session do not contribute to the other channels activated during the session.

An optimal solution may be described for certain values of the parameters C and N.
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- $N=C^2$,
- C is equal to the cardinal of a finite field.

Furthermore, in this case $n=C$ and therefore $N=n^2$.

A lower limit on the number of successive sessions that must be executed in order for each emitter to be able to communicate at least once with all the n^2-1 other users is defined equal to $n+1$. Specifically, an emitter user makes contact with $n-1$ other emitters in each session. After k sessions it has at best communicated at least once with $k(n-1)$ other emitters. Therefore, to make contact with all the other emitters, at least $n+1$ sessions are required ($n^2-1 =$
25
30 $(n+1)(n-1)$).

In order to meet this condition, n is chosen equal to the cardinal of a finite field F_q . This allows the emissions over each channel to be organized so that all the n^2 emitters are connected with the others at least once during a period of $t = n + 1$ sessions.

5 The method allowing channel allocation matrices to be generated, according to the invention, makes use of a finite field to define a physical allocation of logic channels to a plurality of users or user groups during a transmission session composed of a plurality of time slots. The parameters of allocation of channels to the users in a given frame will be stored in a
10 memory of a radio equipment and called during operation of the radio equipment.

A first step consists in choosing the number of channels C so that $C \geq \sqrt{N}$ and the number of channels so that C is equal to a power of a first number (C is therefore the cardinal of a finite field).

15 A first variant way of generating the allocation parameters consists in generating C matrices from a first matrix, using straight lines of variable slopes to scan the matrix.

Let the following be considered $n = q = C =$ cardinal of a finite field F_q (i.e. $q = p^k$ with p a first number, and $k \geq 1$).

20 Each of the $N = q^2$ users U_i is considered to be a point (x,y) in a plane $E = F_q \times F_q$.

In E , a set of points (x,y) the coordinates of which respect an affine relationship of the following type is called a "straight line":

$$\text{straight line} = \{(x,y), \text{ such that } ax + by + c = 0\}.$$

25 In E , the straight lines are classified by their "slope":

- For each "a" of F_q , there are q straight lines of slope "a" of form:

$$\{(x,y), y = ax+b\}$$

- To these, the q straight lines of "infinite" slope must be added:

$$\{(x,y), x = b\}$$

30 The number of straight lines in the plane $(F_q \times F_q)$ is therefore: q^2+q .

It may easily be verified that:

- a) Each straight line comprises q points (x,y) ,
- b) Two distinct straight lines of same slope do not cross (no intersection),
- c) Two straight lines of different slopes always cross, and at a single point,
- 5 d) Any two given distinct points belong to a single straight line.

In particular, for each slope “ a ” (a in F_q , or “infinite”) the q straight lines of given slope “ a ” form a partition of the plane $E = F_q \times F_q$ (since they are of empty intersection, of cardinal q and q in number, their union indeed includes the $q \times q = q^2$ points of E).

10 The method deduces therefrom an optimal assignment of the emitters to the $C = q$ channels in $t = (q+1)$ sessions.

- 1) A point (x,y) on the plane E is bijectively associated with each user,
- 2) A slope $a(k)$ of $F_q \cup \{\text{infinite}\}$ is bijectively associated with each session k , $0 \leq k < q+1$,
- 15 3) In F_q a parameter $b(i)$ is bijectively associated with each channel $0 \leq i < q$,
- 4) Assignment rule: the channel i in the session k is assigned to the q users the coordinates (x, y) of which are the q points of a specific straight line of slope $a(k)$,

20 which is to say, more precisely:

- if $a(k) \neq \text{infinity}$, $\{(x,y) \in E, y = a(k) x + b(i)\}$
- if $a(k) = \text{infinity}$, $\{(x,y) \in E, x = b(i)\}$

With this assignment, each user is connected once and only once to another during the $t = q+1$ sessions. Specifically, the $q+1$ sessions use all the (q^2+q) possible straight lines, and only a single straight line passes through two points.

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This assignment is illustrated in Figure 2, which shows two channel allocation matrices in which the columns correspond to a slot, the rows to channels to be allocated, and the content of the matrix to the number of a user or a group (for example a pair or triplet) of users. The first matrix $M1$ corresponds to a straight line of zero slope (reference matrix). The second

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matrix M2 was generated by scanning the first matrix with a straight line of non-zero slope (slope 1). Figure 3 shows a concrete example in which, for the sake of clarity, only three matrices of the 12 have been shown. The third matrix M12 is generated with an infinite slope. The method thus generates
5 C+1 matrices of channels to be allocated to the users.

This variant of construction of the channel allocation matrices is defined for the case of doublets (N, C) of the form (q^2, q) where q is the cardinal of a finite field (i.e., a number of the form p^k , p first number, $k \geq 1$).

According to one variant embodiment, to handle cases where the
10 number of users and/or the number of channels is not ideal, two techniques will be described.

The first technique allows a number of users that is not equal to the square of the cardinal of a finite field to be handled. The number of users is considered to be equal to N . Let q be the smallest suitable number
15 (coordinate of a finite field) such that $q^2 \geq N$ (and such that q^2 is different from N).

The principle is to consider $q^2 - N > 0$ users for the assignment law and to make the other $q^2 - N$ users inactive (or virtual) users. If nothing is optimized, the period of the complete transmission is $q(q+1)$, if a session of
20 q users is considered to have a duration equal to q . It is possible, if N is substantially lower than q^2 , to optimize the duration.

To do this, if there are at least $k \cdot q$ ($k \geq 1$) inactive users (i.e.: $q^2 - k \cdot q \geq N > q^2 - (k+1) \cdot q$), the inactive users are optimally chosen so as to decrease the total period. To do this, the $k \cdot q$ inactive users are assigned to k
25 logic channels in the same session (the last). These logic channels contain only these $k \cdot q$ inactive users. This amounts to choosing, as inactive users, users located on the same logic channel in the last session of the period.

The q other sessions contain at most $q - k$ users per logic channel (the users of a logic channel in a session are distributed over the logic
30 channels for each of the other sessions), thereby allowing the duration of the

other sessions to be decreased by k . The frame duration (or period) is therefore $q+q*(q-k)=q*(q-k+1)$.

A concrete example is given below. For $N=110$ users, q is set equal to 11. Thus, $q^2=121$. There are 11 inactive channels. An assignment law applied to the logic channels leads to 12 sessions of a size of 11. In one session (for example the last), the users of the last logic channel are inactive. The other sessions have only 10 users for each logic channel and therefore a duration decreased to 10. The duration of the period may therefore be decreased to 10 for each of the first 11 sessions and to 11 for the last session i.e. 121 (instead of 132). Figure 4 indicates the matrices corresponding to this solution (only 3 of the matrices have been shown: the two first and the last). A period's worth of duration is therefore saved each time there is a multiple of 11 inactive users. The saving therefore increases in steps (the total period would have been the same with 100 users). This amounts to considering users 0 to 109 in Figure 3: for the 11 first matrices, the rows are 10 in length.

A second technique makes it possible to handle the case where the number of available logic channels is insufficient. Let there be q available logic channels and let the number of users be $N > q^2$. It is possible to group the users together into groups of at most k users such that $(k-1)*q^2 < N \leq k*q^2$.

Let the case where the number of users is of the form $N=k*q^2$ be considered. Therefore, there are groups of users $GrU_0=\{U_0, U_{q^2}, \dots, U_{(k-1)*q^2}\}$; $GrU_1=\{U_1, U_{q^2+1}, \dots, U_{(k-1)*q^2+1}\}; \dots; GrU_i=\{U_i, U_{q^2+i}, \dots, U_{(k-1)*q^2+i}\}; \dots$. There are $M=N/k=q^2$ groups of users.

The algebraic construction is applied to the M groups of users in an identical way to the way used for the M elementary users (the users of a given group successively transmit over the same logic channel in all the sessions).

There are therefore $q+1$ sessions. In each session, there are q channels in parallel. In each channel of each session, q groups of k users (i.e. $k*q$ users) exchange information. Users located in a given group

therefore exchange their positions in each session. The total duration of the transmission period is equal to $(q+1)*q*k$.

The following concrete example, for $N = 242$, $q = 11$, will allow this variant to be better understood. 121 groups of two users are formed. There are 12
 5 matrices of $11*11$ size of groups of users, i.e. 12 matrices of $11*22$ size (11 in channel dimension, 22 in the dimension of the number of users and therefore of the occupied time resource). This gives a total frame size of $12*22=264$.

The two techniques may be combined. It is a question of treating
 10 the case where N is higher than q^2 but for which there is no integer k such that $N=k*q^2$.

k is chosen such that $(k-1)*q^2 < N < k*q^2$.

The law used to assign the logic channels to the q^2 groups of users is determined. There are therefore $q+1$ sessions. In each session, q logic
 15 channels each contain q groups of users. If the position of the inactive users is not optimized, the total period is equal to $(q+1)*q*k$.

If the number of inactive users is higher than or equal to q , the choice of the inactive users allows the total period of the transmission to be decreased.

If q users are inactive, the q inactive users are positioned on the same logic
 20 channel of the first session, in an amount of one inactive user per group of users. This means that the size of the groups of users is decreased by 1 for this particular session.

For each of the following sessions, one of the groups of users of the session has a size decreased by 1 and the duration of the session is decreased by 1.

25 The total duration of the period becomes: $k*q*(q+1)-q$.

If the number of inactive users is a multiple of q ($m*q$), the $m*q$ inactive users are positioned on m logic channels of the first session. This means that the size of the groups of users is decreased by 1 for all the groups belonging to
 30 m logic channels of the first session. For each of the following sessions, the cumulative size of the groups of users of the session is decreased by m and

the duration of the session is decreased by m . The total duration of the period becomes: $k*q*(q+1)-q*m$.

A concrete example is given for $N = 220$ users and $q = 11$ available logic channels. The case where $q=11$, i.e. where $q^2=121$, is treated. It will be noted
 5 that $N=2*q^2-22$. Therefore, $k=2$ and $m=2$. 121 groups of two users (242 users, 22 inactive users of which are to be positioned) are formed. There are 12 matrices of $11*11$ size of groups of users, i.e. 12 matrices of a size of $11*22$ (11 in channel dimension, 22 in time dimension) users. This gives a total size of $12*22=264$. The inactive users are positioned on two logic
 10 channels of the first session, in amount of one inactive user for each group of these two channels.

There are therefore, for the first session, 9 “complete” logic channels comprising groups of 2 size and two logic channels of reduced size comprising groups of 1 size.

15 For the 11 following sessions, each logic channel contains exactly nine groups of 2 size and two groups of 1 size. The period of the session is therefore $2*9+2=20$.

The total period is therefore equal to $22+11*20=242$.

The invention on the one hand presents an optimal way of
 20 allocating sessions and logic channels to users, for certain values of the number of users and of the number of available logic channels. The invention on the other hand presents methods allowing any value of the number of users and of the number of available logic channels to be treated, on the basis of one of the optimal solutions. The degradation with respect to the
 25 optimal solution remains very limited and the obtained solution is therefore high-performance.

CLAIMS

- 1 – Method for allocating communication logic channels to N users in a network, comprising at least the following steps:
- 5 a) defining a first allocation set composed of the following triplets (channel number, slot number, user attributed to a channel for a given slot) representing the allocation of C communication channels, to the N users, in a first time session composed of a plurality of time slots, with the number C of communication channels equal to the square root of the number of users N and C equal to the cardinal of a finite field,
 - 10 b) generating, from the first channel allocation set, C other matrices, each matrix describing the allocation of the users to the communication channels during a session, said C allocation matrices being generated using a function configured so that each user is in communication with each of the other (N-1) users at least once during the frame containing the C+1 sessions, the communication actually taking place if the users are in communication range.
- 2 – Method according to Claim 1, characterized in that the allocation set takes the form of a matrix and in that an allocation matrix is generated from
20 the first allocation matrix by scanning the columns and rows of the matrix using straight lines of variable slopes.
- 3 – Method according to either of Claims 1 and 2, characterized in that in the case where the relationship $C = \sqrt{N}$ is not satisfied, a number of inactive
25 users is chosen and $N' > N$ active or inactive users, with $C = \sqrt{N'}$, are treated and the position of the inactive users is optimized to minimize the size of the frame.
- 4 – Method according to one of Claims 1 to 3, characterized in that, in the
30 case where the number of available channels is lower than the square root of the number of users, the users are grouped together into subgroups of at

most k users with $(k-1) \cdot q^2 < N \leq k \cdot q^2$ where q is the number of available channels.

5 5 – Method according to Claim 4, characterized in that a group of users is composed of a plurality of subsets of users, such as pairs, triplets and/or single users.

10 6 – Method for sharing data between a plurality of users, comprising the step of allocating communication channels according to one of Claims 1 to 5 and a step in which the users exchange their positions and the positions of their neighbours in radio range.

15 7 – Method according to Claim 6, characterized in that the users are radio equipment.

20 8 – Device for allocating communication channels to a plurality of users U_i in a network, characterized in that it comprises a device (30) configured to execute the steps of the method according to one of Claims 1 to 7, and means for storing the set including the allocation of the channels C as a function of a slot S and for a user.

25 9 – Device according to Claim 8, characterized in that each user is equipped with a processor (12i) configured to execute the steps of the method according to one of Claims 1 to 7.

10 10 – Device according to either of Claims 8 and 9, characterized in that a user is a radio equipment and the network is an ad-hoc communication network.