

METHOD AND DEVICE FOR COMPUTING STATISTICAL PARAMETERS OF THE PROPAGATION CHANNEL

The invention relates to a method and a device making it possible to
5 dynamically compute the statistical parameters of the propagation channel in
a communication system. It makes it possible in particular to dynamically
allocate transmission parameters in random channels for wireless networks.
It can be used in the field of telecommunications. It allows the management
of the use of the physical resources in wireless networks of ad hoc type. It
10 finds its application in embedded systems.

One of the problems posed is to allocate resources, for example,
the power, the coding and modulation scheme, in an optimal manner to the
various nodes of a network so as to maximize the performance of this
network, doing so in a dynamic manner in order to be able to adapt the
15 network permanently to the propagation conditions which evolve according to
the mobility of the nodes.

Solutions exist which make it possible to allocate the physical
resources in a mono-user context and which are based on estimation of the
statistic of the propagation channel. However, the existing solutions consider
20 that this statistic does not vary over time. But, communicating terminals being
mobile, the statistic is liable to vary over time. It is therefore important to
estimate this statistic in real time so as to be able to use the physical
resources in an optimal manner.

The prior art can be classified into three approaches: the
25 estimation of the statistic of the channel and of the associated power
allocation [1-2], the estimation of the statistic of the channel [3-4] and the
allocation of power based on statistical knowledge of the channel [5].

In [1], the authors propose a power allocation strategy by
considering the Nakagami-m channel. The authors also propose various
30 estimators of the statistical parameters of this channel, and evaluate the
performance of their power allocation algorithm when the statistic of the

channel is estimated. In [2], a power allocation method based on an estimation of the statistic of the Nakagami-m channel is proposed.

There exists a large number of references dealing with the estimation of the statistic of the Rice channel. In [3], the authors mention the use of a sliding window to deal with the case of a statistic that may vary over time. In [4], the authors estimate the statistic of the Rice channel on the basis of real data, by using a sliding window as proposed in [3]. None of these references deals with the resources allocation problem.

In [5], a power allocation aimed at minimizing the transmission power in a multi-user context is performed, when the statistic of the channel is considered to be known perfectly.

In the methods known from the prior art, the statistic of the channel is considered to be constant, except in [4] where a sliding window of constant size is used. However, in real communications systems, this statistic is liable to vary more or less rapidly over time owing to the mobility of the terminals. Furthermore, the allocation of resources which is carried out in these works is focused on mono-user contexts, with the objective of maximizing or minimizing a single cost function.

The technical teaching of document WO 01/59963 relates to a method and a system for computing the Rice factor in real time or quasi-real time. This document uses a periodic and non-sliding time window to estimate the statistic of the channel, estimating that the use of a sliding window is too expensive. Moreover, it neither mentions nor suggests the detection of a possible break.

The idea of the present invention consists notably in estimating the statistic of the channel in real time. This estimation is carried out via the use of a sliding window (that may be of variable size), combined with the use of tools arising from break detection. The sliding window makes it possible to track the variations of the channel's statistic when the latter evolves continuously over time. The size of the window is adapted to suit the speed of variation of the statistic: the more rapidly the statistic varies, the smaller

the window will be in order to best track the evolution of the statistic. Tools for break detection make it possible to track the discontinuous evolutions of the statistic, for example, when passing from a configuration with no line of sight between the transmitter and the receiver to a configuration with a strong transmitter/receiver line of sight. These tools make it possible to detect this type of discontinuity so as to best track the evolution of the statistic.

The invention relates to a method for computing in real or quasi-real time, the values of the statistics of a propagation channel so as to allocate resources to one or more communication links between two nodes in a communication network comprising at least the following steps:

Estimate in real or quasi-real time the statistical parameters K_l which corresponds to the ratio between the power of the signal received in direct line of sight and the power of the diffuse paths and G_l which corresponds to the mean gain-to-noise ratio of a Rice channel model modelled for each link l of the network by using the information from training sequences contained in the received signal which make it possible to estimate the propagation channel,

On the basis of the propagation channel estimations stored, at the level of a receiver, execute the following steps in parallel:

- detect whether there is a change in the statistical distribution of the estimations of the channel manifesting a break,

If a break is detected, preserve part of the estimations of the channel, and estimate the statistic K_l , by using part $T_w/2$ of the estimations of the propagation channel with T_w the number of estimations of the channel used to perform the break detection,

Otherwise, when no break is detected, estimate the statistic K_l of the channel, performed over the last T_w estimations of the channel,

- estimate the statistic G_l of the channel by using a sliding time window,

Transmit the values of channel statistics computed to a step of allocating the resources which takes into account the service constraints and defines the

allocation of the resources as a function of the estimations of the statistics of the channel.

To detect a break, one computes, for example, the phase for each estimated sample of the channel, the set of computed phases is separated
 5 into two subsets and the two statistical distributions thus obtained are inter-compared, if a change in the statistical distributions is detected, only one of the two subsets is preserved, otherwise all the estimations of the channel are preserved.

The comparison of the content of the two statistical distributions
 10 can be performed using a test based on the statistical likelihood of the estimations of the channel, with the aid of statistical tests of fit with two samples.

The parameter K_l manifesting a relation between the power of the line of sight path and the power of diffuse paths is estimated, for example, by
 15 maximizing the statistical log-likelihood of the phase of the estimations of the channel.

The method may also comprise a step of computing the statistics of the channel and a step of transmitting the computed statistics of the channel to a resources manager, the said resources manager allocating the
 20 resources to the communication links of the ad hoc network.

The method may also comprise a step of computing the statistics of the channel according to the steps indicated hereinabove and a step of transmitting the channel statistics computed within a communication link between a transmitter and a receiver, and each communication link decides
 25 the allocation of the resources as a function of the constraints.

A transmission power, a proportion of the frequency band used within the ad hoc network as well as a modulation and coding scheme is allocated to each communication link, the said parameters being allotted so as to maximize or to minimize one or more of the said quantities: the total
 30 energy power or the sum of the bitrates of the communications links.

The model used for the modelling of the channel is a Rice model.

The invention also relates to a system for computing the statistics of a propagation channel so as to allocate resources in a communication network comprising several communication links, characterized in that it comprises a resources allocator and a processor which is configured to execute the steps of the method according to the invention.

The resources allocator may be included in a terminal distinct from the transmitters/receivers of the communication links to which resources are allocated.

The invention also envisages a system for allocating resources in an ad hoc communication network, characterized in that each transmitter/receiver of a communication link requesting an allocation of resources is configured to execute the steps of the method according to the invention.

Other characteristics and advantages will become better apparent on reading the description which follows together with the figures which represent:

- Figure 1, an exemplary ad hoc network with resources allocator, and Figure 2, the uploading of the statistics,
- Figure 3, an exemplary ad hoc network without resources allocator, and Figure 4, the uploading of the statistics,
- Figure 5, an example of the steps for the procedure for estimating and allocating the resources,
- Figure 6, a detailed example of the procedure for estimating the statistics,
- Figure 7, a detailed example of the break detection procedure.
- Figure 8, a detailed example of the estimation procedure based on a sliding window.

The description which follows is given by way of wholly nonlimiting illustration while considering a network composed of communication links between two mobile nodes communicating with one another. One of the objectives of the present invention is to assign physical resources to the

communication links, in terms of transmission power, frequency band and modulation and coding scheme based solely, under normal operation of the network, on statistical knowledge of the propagation channel. This makes it possible in particular to avoid an excessive exchange of information in the
5 network so as to reduce the necessary signalling.

Various configurations can be envisaged. As is illustrated in Figure 1, the system can comprise a first communication link 10 with a transmitter Tx1 and a receiver Rx1, a second communication link 20 having a transmitter Tx2 and a receiver Rx2, and a terminal 30 elected to be manager of the
10 resources. The communication link is defined between two nodes, not represented, of the communication network. In a regular manner, the transmitters transmit training sequences so as to estimate the propagation channel. These estimations of the channel are stored in a memory 11, 21 next to the receiver Rx1, Rx2. In this case each receiver groups together the
15 statistical information of the links to the resources manager, as is illustrated in Figure 2. The terminal 30 in addition to the communication means known from the prior art comprises a processor 31 configured to execute the steps of the method according to the invention and a resources allocator 32 or resources manager. On the basis of the estimated statistical values, the
20 terminal 30 will be able to carry out the allocation of resources, using a procedure known to the person skilled in the art. The resources manager 32 allots a transmission power, a proportion of the frequency band B, as well as a modulation and coding scheme MC to each communication link 10, 20. These parameters are allotted so as to maximize or minimize one or more
25 quantities. For example, it is possible to determine the aforementioned parameters so as to minimize the total energy consumption under the bitrate constraints for certain users, while for other communication links, the objective may be to maximize their bitrate under maximum transmission power constraints.

The allocation can be carried out either by one of the parties to the communication (transmitter or receiver), or else by a different device from the transmitters/receivers, which is external to the communication link.

To summarize, the method in this variant embodiment estimates
5 the statistic of the channel as will be detailed hereinafter. If the statistic of the channel has varied, the information is uploaded from a communication link 10, 20, to the terminal 30 whose computer 31 or processor then computes the optimal allocation of the resources and whose resources manager 32 indicates in return to the communication links the resources available to
10 them.

In another example illustrated in Figure 3, each communication link 10, 20, computes values of statistics and the receivers of each communication link communicate the statistic of the channel to the associated transmitter. A communication link comprises a resources allocator
15 12, 22 which will carry out the resource allocation in a decentralized manner, according to Figure 4. In this "decentralized" configuration, each communication link of the communication network comprises communication means known from the prior art, a resources allocator 12, 22 and a processor 13, 23, which is configured to execute the steps of the method according to
20 the invention. The processor can be positioned at the level of the transmitter of a link or at the level of a receiver. Each communication link will in this case be able to allocate the communication resources on the basis of the statistical values estimated.

The example detailed hereinafter, given by way of wholly
25 nonlimiting illustration, is based on an orthogonal multiple channel access modulation technique. For example, it is possible to use orthogonal frequency division multiple access or OFDMA modulation or single carrier access modulation SC-FDMA (Single Carrier Frequency Division Multiple Access).

Let L be the number of links in the network. These L links share a frequency band B , which is divided into N_c sub-carriers. The signal received by a receiver at the instant i for the link l on the sub-carrier n may be written:

$$y_l[n, i] := \Lambda_l[i] h_l[n, i] x_l[n, i] + b_l[n, i], \quad (1)$$

- 5 where $x_l[n, i]$ is the signal transmitted on the sub-carrier n at the instant i , $\Lambda_l[i]$ is a real attenuation coefficient which corresponds to the large scale fading at the instant i , $h_l[n, i]$ is a complex attenuation coefficient which corresponds to the small scale fading and $b_l[n, i]$ is complex white noise, considered to be Gaussian, centred and of variance $2\sigma_b^2$. Within the
10 framework of this invention, the variance $2\sigma_b^2$ is considered to be known to the receiver and sufficiently low, as will be detailed hereinafter. This value can be obtained for example via a calibration process known to the person skilled in the art.

- On the link l , a transmitter transmits its signal with a transmission
15 power P_l , with $\mathbb{E}[|x_l[n, i]|^2] = P_l$, where $\mathbb{E}[\cdot]$ is the mathematical expectation operator. γ_l is defined as being the proportion of frequency band allocated to the link l for communicating, and MCS_l the modulation and coding scheme of the link l . Furthermore, we define the set of powers for the L links, $l=1..L$, $\mathbf{P} := [P_1, \dots, P_L]$, the set of the $\boldsymbol{\gamma} := [\gamma_1, \dots, \gamma_L]$ and the set of modulation and
20 coding schemes $\mathbf{MCS} := [MCS_1, \dots, MCS_L]$.

To simplify the written expressions, in equation (1) as well as throughout the subsequent description, the temporal indices are discretized, thus signifying that the instant i corresponds in fact to the instant iT_s with T_s the sampling period.

- 25 In equation (1), the long-term fadings $\Lambda_l[i]$ are composed of the power loss of the transmitted signal with respect to the received signal due to the distance between the transmitter R_{xi} and the receiver T_{xi} , known by the name pathloss in English, and of the power loss due to the presence of large obstacle between the transmitter R_{xi} and the receiver T_{xi} , known as masking
30 phenomenon or shadowing in English. The pathloss is deterministic while the

shadowing is random. These two phenomena are grouped together under the name large-scale fading. Moreover, $\Lambda_l[i]$ varies slowly over time much more slowly than $h_l[n, i]$.

The small-scale fading $h_l[n, i]$ is also attenuations of the transmitted power with respect to the received signal, which are due to physical phenomena such as reflection or diffraction of the signal transmitted. $h_l[n, i]$ varies over time much more rapidly than $\Lambda_l[i]$.

Within the framework of this invention, a well-known statistical model of propagation channel is considered: the Rice channel. Thus, it is considered that $h_l[n, i]$ follows a complex normal law with mean $\mu_l[i]$ and variance $2\sigma_l^2[i]$. Furthermore, without loss of generality, $h_l[n, i]$ is considered to have normalized power, and therefore $\mathbb{E}[|h_l[n, i]|^2] = \Omega_l = 1$. It is thus possible to show that $|h_l[n, i]|$ follows a Rice law with statistical parameters $K_l[i] := \frac{|\mu_l[i]|^2}{2\sigma_l^2[i]}$ and Ω_l . Physically, $K_l[i]$ represents the ratio between the power of the signal received in direct line of sight and the power of the diffuse paths. The method can also be applied to all types of channel models, by adapting the estimators of the statistics of the channel.

With the aid of the notation defined previously, it is possible to define $\check{h}_l[n, i] := \Lambda_l[i]h_l[n, i]$ as a channel coefficient grouping together at one and the same time the small-scale fading and large-scale fading. For constant $\Lambda_l[i]$, $\check{h}_l[n, i]$ follows a Gaussian complex law with mean $\Lambda_l[i]\mu_l[i]$ and with power $\mathbb{E}[|\check{h}_l[n, i]|^2] = \Lambda_l[i]^2$. $\Lambda_l[i]$ varies slowly and can therefore be considered to be constant over a certain temporal duration which depends on the speed of the transmitter and of the receiver. Thus, over this temporal duration, the channel behaves as a Rice channel with statistical parameters $K_l[i]$ and $\Lambda_l[i]^2$. The mean gain-to-noise ratio is defined by:

$$G_l[i] := \frac{\Lambda_l[i]^2}{2\sigma_b^2}. \quad (2)$$

To properly understand the invention, the detailed example which follows is given in the case of a centralized system such as illustrated in

Figure 1. In order to estimate the statistic of the channel, the first operation to be carried out by the processor of a communication link is to estimate the propagation channel $\check{h}[n, i]$. For this purpose, one considers the use of pilot symbols (contained in a signal received at the level of the receiver of a communication link), that is to say symbols which are known to the receiver. Thus, given (1), when $x_n[n, i]$ is known, the channel can be estimated as follows:

$$\hat{h}_l[n, i] = \frac{y_l[n, i]}{x_l[n, i]}$$

Within the framework of a multicarrier communication, the $h_l[n, i]$ (and therefore the $\hat{h}_l[n, i]$) are correlated frequently, that is to say $\hat{h}_l[n_1, i]$ is correlated with $\hat{h}_l[n_2, i]$. However, through simplicity of expression, this correlation is assumed to be negligible, this being realistic when the gap between the sub-carriers allotted to the link l is greater than the coherence band of the channel. Thus, for the subsequent description, the dependency in n will be omitted when making reference to the estimations of the channel. By using equation (2), it is possible to show that, for constant $\Lambda_l[i]$, $\hat{h}_l[i]$ follows a complex normal law with mean $\mu_l[i]$ and with power $\Lambda_l[i]^2 + 2\sigma_b^2/P_l$. In the examples which follow, $\hat{h}_l[i]$ may be written in the following form:

$$\hat{h}_l[i] = \Lambda_l[i] \left(|\mu_l[i]| e^{j(\theta_l^0 + w_0^l i)} + g_l[i] \right) + \hat{b}_l[i]$$

where θ_l^0 is the initial phase of the main component of the received signal, $g_l[i]$ is a Gaussian complex random variable with zero mean and with variance $2\sigma_l^2[i]$, $\hat{b}_l[i]$ is a Gaussian complex random variable with zero mean and with variance $2\sigma_b^2/P_l$ and $w_0^l := 2\pi f_l^d \cos(\beta_l^0)$ with f_l^d the Doppler frequency of the link l and β_l^0 the angle of arrival of the specular component of the link l . Within the framework of the invention, w_0^l is considered to be known. This quantity can be estimated with the aid of the estimators proposed in reference [6] of the prior art and which are therefore not discussed in the description.

The probability density of the phase of the $\hat{h}_l[i]$, denoted $\varphi_l[i]$, can be written as follows, when $2\sigma_b^2 = 0$:

$$p_l(\varphi, \Phi, i) = \frac{1}{2\pi} e^{-K_l} (1 + q(i)\sqrt{\pi}e^{q(i)^2} (1 + \text{erf}(q(i)))) \quad (3)$$

with $q(i) = \sqrt{K_l} \cos(\theta - \theta_l^0 - w_l^0 i)$ and $\Phi_l := [K_l, \theta_l^0]$.

- 5 Equation (3) shows that the statistical distribution of the phase of the $\hat{h}_l[i]$ is non-stationary since it depends on i .

During a first step, the phase of the $\hat{h}_l[i]$ will be rendered stationary via the following operation:

$$\tilde{h}_l[i] := e^{-jw_l^0 i} \hat{h}_l[i]$$

- 10 The probability density of the phase of the $\tilde{h}_l[i]$ may be written as follows when $2\sigma_b^2 = 0$

$$p_l(\varphi, \Phi) = \frac{1}{2\pi} e^{-K} (1 + q\sqrt{\pi}e^{q^2} (1 + \text{erf}(q))) \quad (4)$$

with $q = \sqrt{K} \cos(\theta - \theta_l^0)$.

- 15 In the subsequent description, $2\sigma_b^2$ is considered to be small enough for equation (4) to properly represent the probability density of the phase of the estimated channel samples.

- As was stated previously, one of the objectives of the present invention is to compute the statistical parameters of a propagation channel in real time so as, for example, to carry out an allocation of resources based only on a statistical knowledge of the propagation channel. Thus, the method
20 comprises at least the following two operations:

- 1- Estimate the statistical parameters K_l and G_l of the propagation channel for each link, $l=1\dots L$, this is carried out at the level of each communication link,
- 2- Carry out an allocation of resources based on these estimations of the
25 statistics of the channel, the manager groups together the whole set of statistical information relating to all the links between the communication links.

In the case of the second variant embodiment, decentralized case, each communication link will execute these operations so as to allocate resources on the basis of the estimated statistical parameters of the propagation channel.

5 Figure 5 illustrates the steps executed by the processor of each communication link.

On the basis of the training sequence 51 contained in the signal received at the level of a receiver, the processor of a communication link estimates the channel 52, and then the statistic of the channel 53. This
10 information is transmitted to the resources allocator (or to the transmitter of the communication link 54) so as to carry out the allocation of the resources 55. During the last step 56, the manager of the resources or each receiver of a communication link will undertake the allocation of the resources for a next transmission.

15 The method according to the invention takes into account the temporal variability of the statistic of the channel. For this purpose, two types of variations are considered by way of illustrative example in Figure 6: 1) disruptive variations and 2) temporally continuous variations.

The left part of Figure 6 illustrates the case of the disruptive
20 variations of the statistics of the channel which are liable to occur in particular relating to the value of K_l since this parameter manifests a relation between the power of the direct line of sight path and the power of the diffuse paths. This value can vary, for example, when passing from a communication configuration where a direct line of sight exists between the transmitter and
25 the receiver, to a configuration with no direct line of sight.

After estimation of the channel 61, the processor of a communication link looks at whether there is a detection of break 62. In the case where it detects a break (i.e., break in a communication), the processor estimates $\hat{K}_l$ on the basis of the last $T_w/2$ estimations of the channel, 63.
30 When the processor does not detect any break then the processor will estimate 64 the parameter K_l on the basis of the last T_w estimations of the

channel arising from the step of estimating the channel. Next the processor will transmit the computed statistics to the resources allocator (manager of the network) or to the transmitter of the communication link which has carried out these computations, 65.

5 A disruptive variation of the parameter K_l is manifested as follows:

$$K_l = \begin{cases} K_l^1 & \text{for } i = 1, \dots, T_D \\ K_l^2 & \text{for } i = T_D + 1, \dots, T_W \end{cases}$$

where T_D represents the instant at which the change of value of the statistic occurred, and T_W represents the number of estimations of the channel used to perform the break detection. The break detection problem is expressed in the form of a problem of tests of hypotheses which are written as follows:

$$\begin{aligned} H_0: & \text{the parameter } K_l \text{ is constant } \forall i \in [1, \dots, T_W] \\ 10 \quad H_1: & K_l[i] = K_l^1 \forall i \in [1, \dots, T_D], K_l[i] = K_l^2 \forall i \in [T_D+1, \dots, T_W], \quad \text{the parameter} \\ & \text{varies at the sample } T_D. \end{aligned}$$

The hypothesis H_0 corresponds to the case where K_l has not varied, while H_1 corresponds to the case of a variation of K_l .

As regards the temporally continuous variations of the statistics of
15 the channel, these also occur on account of the mobility of the communication links, the right part of Figure 6 illustrates the use of a sliding window 66 before transmission of the computed statistics, 65. Indeed, $\Lambda_l[i]$ takes account of the power loss due to the distance between the transmitter and the receiver. Typically, it is common to use the relation $\Lambda_l[i] \propto d_l[i]^{-\alpha}$,
20 where $\propto$ signifies a proportionality relation, and d_l is the distance between the transmitter and the receiver of the link l at the instant i and α is an attenuation coefficient lying between 2 and 4. The distance $d_l[i]$ evolves over time owing to the mobility of the communication links, and consequently the power of the received signal will vary over time. Furthermore, $\Lambda_l[i]$ is also
25 subject to random fluctuations, thus also introducing a variation of the power received.

Thus, it is clear that when the statistics of the channel vary over time, it is counter-productive to use the oldest channel estimations since the statistical

distribution of these channel estimations is different from the statistical distribution at the present instant.

In order to be able to take account of these two types of possible variations of the statistics, the method according to the invention uses an approach which combines the use of sliding windows and of tools arising from break detection so as to best estimate the statistic of the channel in order to carry out the associated optimal resource allocation.

Hereinafter, the approach based on break detection is detailed. Break detection is aimed at detecting whether K_l (parameter of the Rice channel) has varied in a disruptive manner over time.

By way of example, the subsequent description bases the detection of break of the parameter K_l on the phase of the channel estimations so as to circumvent the non-stationarities introduced by the masking effects. With this in mind, the method uses, for example, non-parametric break detection procedures, in the manner of [7].

The idea of the present invention is also to offer a not very complex system. For this purpose, Figure 7 illustrates an example for executing the break detection procedure. A number T_W of channel estimations $[\tilde{h}_l[1], \dots, \tilde{h}_l[T_W]]$ is available 71. The phase of each of these channel estimations is computed. This set of phases $\varphi = [\varphi_1, \dots, \varphi_{T_W}]$ is divided into two subsets of size $T_W/2$: $\varphi_1 := [\varphi_1, \dots, \varphi_{T_W/2}]$ 72 and $\varphi_2 := [\varphi_{\frac{T_W}{2}+1}, \dots, \varphi_{T_W}]$ 73. The statistical distributions of φ_1 and φ_2 are then compared, 74, test on K_l . If no change in the statistical distributions is detected, then the break detection procedure ends until the arrival of the estimated sample of following channel, $[\hat{h}_1, \dots, \hat{h}_{T_W}]$, 75. If a break is detected, the samples of φ_1 are deleted from the memory so as to retain only those of φ_2 , $[\hat{h}_{\frac{T_W}{2}+1}, \dots, \hat{h}_{T_W}]$, 76.

Any statistical test of a fit to the data can be chosen to compare the distributions of φ_1 and φ_2 . For example, it is possible to use the statistic Z_C arising from [8] which may be written as follows:

$$Z_C = \frac{1}{T_W} \sum_{k=1}^2 \sum_{m=1}^{T_W/2} \log\left(\frac{T_W}{2m-1} - 1\right) \log\left(\frac{T_W}{R_{km} - 0.5} - 1\right)$$

where R_{km} is the rank of $\varphi_{k(m)}$ in φ , with $\varphi_{k(m)}$ the m^{th} largest element of φ_k in φ . The statistic Z_C is thereafter compared with a threshold, obtained by Monte-Carlo simulation, for example. If the statistic is less than the threshold, then a break is detected. In the converse case, no break is detected.

5 According to another variant embodiment, the method uses a sliding window based estimation aimed in particular at estimating K_l and G_l at one and the same time.

The estimation based on a sliding window illustrated in Figure 8 consists simply in using only the last estimated channel estimations to carry
10 out the estimation of K_l and G_l .

For this purpose, the method will adapt the size of the sliding window to the variability of the statistics of the channel, the variability of the signal power received being related to the relative speed of the receiver with respect to the transmitter. Thus, a proportional window size evolving in a
15 manner proportional to the inverse of the relative speed could be adopted, this being manifested as follows:

$$T_{F,G_l} \propto \frac{1}{v_{R,l}}, \quad (5)$$

where $v_{R,l}$ is the relative speed of the transmitter with respect to the receiver on the link l .

20 P channel estimations $[\tilde{h}_1, \dots, \tilde{h}_P]$ are available, 81, statistics of the channel are computed 82, then the oldest sample is deleted 83, before adding the new channel estimation 84. For example, for the estimation of G_l , $P = T_{F,G_l}$.

The estimators of the statistic of the propagation channel will be explained.

25 As $2\sigma_b^2$ is known, estimating G_l amounts to estimating $\Lambda_l[i]^2$. When $\Lambda_l[i]^2$ is constant over a certain temporal duration, this parameter corresponds to the moment of order two of the channel and can be estimated via the following equation:

$$\hat{\Lambda}_l[i]^2 = \sum_{k=1}^{T_{F,G_l}} |\hat{h}_l[k]|^2 - \frac{2\sigma_b^2}{p_l}. \quad (6)$$

An estimation of G_l is then obtained through the formula

$$\hat{G}_l = \frac{\hat{\Lambda}_l[i]^2}{2\sigma_b^2}$$

The estimation of K_l can be performed using 1) the moduli of the channel estimations, 2) the phase of the estimations of the channel or 3) the complex samples of the channel estimations.

In order to free us from the masking effects in the estimation of the parameter K_l , this estimation will be made using the phase of the channel estimations. For this purpose, the approach described hereinafter uses the maximization of the log-likelihood of the phase of the channel estimations.

In practice, the channel estimations are correlated in frequency, but also in time. However, in order to allow analytical developments and to not depend on a specific correlation model, we will make the hypothesis that the channel estimations can be considered to be temporally decorrelated. This hypothesis is realistic if the estimations are carried out at instants separated by a sufficiently long period of time. The channel estimations being considered to be independent, it is thus possible to write the likelihood of the phase of the channel estimations through the following formula:

$$L(\boldsymbol{\varphi}, \boldsymbol{\Phi}) = \prod_{i=1}^{T_K} p_l(\varphi_i, \boldsymbol{\Phi}) \quad (7)$$

where T_K is the number of channel estimations available for carrying out the estimation. In particular, $T_K = T_w/2$ when a break has been detected, and in the absence of break detection, $T_K = T_w$ is the size of the estimation window. For example, it is possible to choose $T_K = T_{F,G_l}$. According to equation (7), the log-likelihood may be written as follows

$$\log(L(\boldsymbol{\varphi}, \boldsymbol{\Phi})) = \sum_{i=1}^{T_K} \log(p_l(\varphi_i, \boldsymbol{\Phi}))$$

The estimation of the parameter K_l is based on the maximization of the log-likelihood of the data. We thus propose the following estimator:

$$\hat{\Phi} = \underset{\Phi}{\operatorname{argmax}} \log(L(\varphi, \Phi))$$

The proposed estimator corresponds to the maximum likelihood applied to the phase of the channel estimations.

In practice, the proposed estimation procedure comprises a first step of rough estimation based on a grid, and a second step based on a
 5 Newton's method.

For the first step, a grid of the form $[0, K_{\max}] \times [0, 2\pi]$ is firstly considered, where $K_{\max}$ is a maximum value for K . Typically, it is possible to fix $K_{\max}$ at 10 or 20 according to the applications and the desired complexity, knowing that increasing $K_{\max}$ increases the complexity of this first step. The
 10 two intervals $[0, K_{\max}]$ and $[0, 2\pi]$ are discretized. $[0, K_{\max}]$ is discretized with a stepsize of K_{stepsize} and $[0, 2\pi]$ with a stepsize of θ_{stepsize} . The rough estimation consists in computing the likelihood of the data for all possible combinations of $[0, K_{\max}]$ and $[0, 2\pi]$, that is to say for all pairs $(pK_{\text{stepsize}}, q\theta_{\text{stepsize}})$ with p and q being positive integers or zero chosen
 15 such that $pK_{\text{stepsize}} \leq K_{\max}$ and $q\theta_{\text{stepsize}} \leq 2\pi$. The pair $(p^*K_{\text{stepsize}}, q^*\theta_{\text{stepsize}})$ which maximizes the log-likelihood of the data is preserved. This first step makes it possible to obtain a coarse estimation of Φ which will serve as initialization during the second step.

The rough estimation of the first step is thereafter used in a second step as
 20 initialization of a Newton's method to obtain a more precise estimation. Newton's method is an iterative method, and the expression serving to compute the iteration $k + 1$ is the following:

$$\hat{\Phi}_l^{k+1} = \hat{\Phi}_l^k - (\mathbf{H}_l^k)^{-1} \mathbf{g}_l^k$$

where $\mathbf{g}_l^k$ is the gradient vector of the log-likelihood of the data, evaluated in $\hat{\Phi}_l^k$, and $\mathbf{H}_l^k$ is the Hessian matrix of this log-likelihood, also evaluated in $\hat{\Phi}_l^k$.

25 These two quantities are expressed as follows:

$$\mathbf{g}_l^k = \begin{pmatrix} \frac{\partial \log(L((\boldsymbol{\varphi}, \hat{\boldsymbol{\Phi}}_l^k))}{\partial K_l} \\ \frac{\partial \log(L((\boldsymbol{\varphi}, \hat{\boldsymbol{\Phi}}_l^k))}{\partial \theta_l^0} \end{pmatrix}$$

$$\mathbf{H}_l^k = \begin{pmatrix} \frac{\partial^2 \log(L((\boldsymbol{\varphi}, \hat{\boldsymbol{\Phi}}_l^k))}{\partial K_l^2} & \frac{\partial^2 \log(L((\boldsymbol{\varphi}, \hat{\boldsymbol{\Phi}}_l^k))}{\partial \theta_l^0 \partial K_l} \\ \frac{\partial^2 \log(L((\boldsymbol{\varphi}, \hat{\boldsymbol{\Phi}}_l^k))}{\partial \theta_l^0 \partial K_l} & \frac{\partial^2 \log(L((\boldsymbol{\varphi}, \hat{\boldsymbol{\Phi}}_l^k))}{\partial \theta_l^{0^2}} \end{pmatrix}$$

The computations of the derivatives contained in the gradient and the Hessian matrix are easily executed by a person skilled in the art and are not reported in this document.

Newton's method is known to converge in a quadratic manner when the initialization lies in the neighbourhood of the optimal solution. Thus, the first
 5 coarse estimation is aimed at ensuring fast convergence towards the maximum-likelihood estimators.

The proposed estimator exhibits the advantages of not depending on a particular correlation model, of being insensitive to the multiplicative masking
 10 phenomenon, and of using the whole phase information available in the channel estimations.

The following table summarizes the tools and the methodology developed for estimating the statistical parameters of the channel.

	K_l	G_l
Tracking	1-Break detection based on the phase or 2-Sliding window	Sliding window of size proportional to the inverse of the speed (equation (5)).
Estimation	Maximum likelihood of the phase	Estimator based on the moduli (equation (6))

To summarize, break detection is performed so as to track the abrupt variations of K_l . When no abrupt variations are detected, a sliding window is used to estimate this parameter.

As regards G_l , this parameter is always estimated via a sliding window,
 5 whose size can be adapted to the relative speed of the transmitter with respect to the receiver.

Once the receivers have estimated the statistic of their channel, being given the configurations of networks considered, according to the variant embodiment illustrated in Figure 1 for the centralized case, the
 10 receivers will communicate the statistic of their channel to the resources allocator. According to the second variant embodiment illustrated in Figure 2, the receivers communicate the statistics to the transmitter.

In the first case, the resources allocator will solve an optimization problem of the type:

$$\underset{E, \gamma, MCS}{\text{maximize}} \quad f(E, \gamma, MCS, \hat{K}, \hat{G})$$

$$\text{under the constraint:} \quad g_i(E, \gamma, MCS, \hat{K}, \hat{G}) \leq 0, i = 1, \dots, N_c$$

15 where f represents the objective function of the problem, which depends on the optimization variables and on the estimated statistics, the functions g_i represent minimum constraints to be complied with, $\hat{K} = [\hat{K}_1, \dots, \hat{K}_L]$ and $\hat{G} = [\hat{G}_1, \dots, \hat{G}_L]$. For example, in [5], the problem of minimizing the power under constraints of minimum bitrate and of maximum power is solved. Thus,
 20 in this reference, f corresponds to the sum of the powers consumed by the various users and the g_i correspond to maximum bitrate and power constraints.

Note that it could be possible to deal with multi-objective approaches. For example, it could be possible to minimize the transmission
 25 power of certain links under constraints of minimum bitrate, and to maximize the bitrate of the remaining links under constraints of maximum powers. This type of problem could be solved in a greedy way by solving firstly the problem of minimizing the power, and secondly the problem of maximizing

the bitrates of the other links by using the remaining resources on completion of the first step.

In the second case where the receivers communicate their estimate of the statistic only to the transmitter, the frequency band is no longer considered to be an optimization variable since the receivers cannot choose which sub-carriers to use in an autonomous manner. Thus, each transmitter must solve an optimization problem of the following form:

$$\begin{aligned} & \underset{E_l, MCS_l}{\text{maximize}} && f(E_l, MCS_l, \hat{K}_l, \hat{G}_l) \\ & \text{under the constraint:} && g_i(E_l, MCS_l, \hat{K}_l, \hat{G}_l) \leq 0, i = 1, \dots, N_c \end{aligned}$$

for example, it is possible to deal with the problem of minimizing the transmission power under a bitrate and maximum power constraint.

The method according to the invention makes it possible in particular to better allocate the resources (power, coding and modulation scheme), to the various nodes of a network so as to maximize the latter's performance, doing so in a dynamic manner in order to be able to adapt permanently to the evolutions of the propagation conditions which vary according to the mobility of the nodes. It allows dynamic optimization of power of each station taking into account the mobility and the potential interference and the best use of the power according to a given criterion, under a bitrate constraint, or maximization of the bitrate under a constraint of maximum power or by combining the two criteria.

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CLAIMS

- 1 – Method for computing in real or quasi-real time, values of the statistics of a propagation channel so as to allocate resources to one or more communication links between two nodes in a communication network comprising at least the following steps:
- Estimate in real or quasi-real time statistical parameters K_l which corresponds to the ratio between the power of the signal received in direct line of sight and the power of the diffuse paths and G_l corresponding to the mean gain-to-noise ratio of a Rice channel model modelled for each link l of the network by using information cues originating from training sequences contained in a received signal which make it possible to estimate the propagation channel, (61),
- On the basis of the propagation channel estimations stored, at the level of a receiver, execute the following steps in parallel:
- detect whether there is a change in the statistical distribution of the estimations of the channel manifesting a break, (62),
 - If a break is detected, preserve part of the estimations of the channel and estimate the statistic K_l , by using part $T_w/2$ of the estimations of the propagation channel with T_w the number of estimations of the channel used to perform the break detection,
 - Otherwise, when no break is detected, estimate the statistic K_l of the channel over the last T_w estimations of the channel, (64),
 - estimate the statistic G_l of the channel by using a sliding time window, (66),
- Transmit (65) the values of channel statistics computed to a step of allocating the resources which takes into account service constraints and defines the allocation of the resources as a function of the estimations of the statistics of the channel.
- 2 – Method according to Claim 1, characterized in that in order to detect a break, one computes a phase for each estimation of the channel of the

channel, the set of computed phases is separated (72, 73) into two subsets and the statistical distributions of the phases of the two sets are inter-compared, if a change in the statistical distributions is detected, only the estimations of the channel corresponding to one of the two subsets (75) are
5 preserved, otherwise all the estimations of the channel (76) are preserved.

3 – Method according to Claim 2, characterized in that the content of the two statistical distributions is compared by using a test based on the statistical likelihood of the phases of the channel estimations, with the aid of statistical
10 tests of fit with two samples.

4 – Method according to Claim 1, characterized in that the parameter K_l manifesting a relation between the power of the line of sight path and the power of diffuse paths is estimated by maximizing the log-likelihood of the
15 phase of the estimations of the channel.

5 – Method for allocating resources in a network of ad hoc type according to Claim 1, characterized in that the step of allocating the resources for each communication link of an ad hoc network is performed by a different device
20 from the transmitters/receivers at the communication link.

6 – Method for allocating resources in a network of ad hoc type according to Claim 1, characterized in that the step of allocating the resources is executed by each of the communication links of the ad hoc network as a function of the
25 constraints.

7 – Method according to one of Claims 5 or 6, characterized in that a transmission power, a proportion of the frequency band used within the ad hoc network as well as a modulation and coding scheme is allocated to each
30 communication link, the said parameters being allotted so as to maximize or

to minimize one or more of the said quantities: the total energy power or the sum of the bitrates of the communications links.

- 8 – System for computing the statistics of a propagation channel so as to
- 5 allocate resources in a communication network comprising several communication links (10, 20), characterized in that it comprises a resources allocator (12, 22, 32) and a processor which is configured to execute the steps of the method according to one of Claims 1 to 7.
- 10 9 – System for allocating resources according to Claim 8, characterized in that the resources allocator (32) is included in a terminal (30) distinct from the transmitters/receivers (Tx1, Rx1, Tx2, Rx2) to which resources are allocated.
- 10 – System for allocating resources according to Claim 9 in an ad hoc
- 15 communication network, characterized in that each transmitter/receiver (Tx1, Rx1, Tx2, Rx2) requesting an allocation of resources is configured to execute the steps of the method according to one of Claims 1 to 7.