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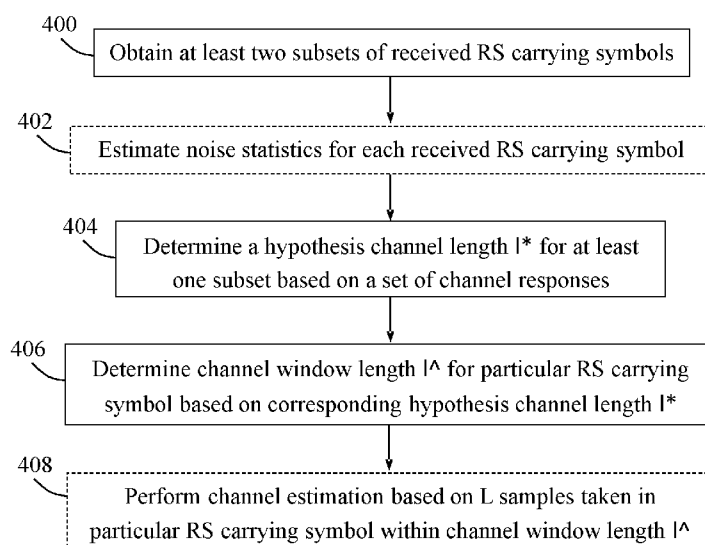


Fig. 4

(57) **Abstract:** A method and a receiving node (100) for determining a channel window length ($l^$) for a transformed domain channel estimator, the channel window length ($l^$) to be applied for a particular reference signal (RS) carrying symbol. At least two subsets ($A_1, A_2, \dots$) of received RS carrying symbols are obtained out of a set of RS carrying symbols ($\{S_1, S_2, \dots\}$), where the particular RS carrying symbol is comprised in at least one of the at least two subsets ($A_1, A_2, \dots$). A corresponding hypothesis channel window length (l^*) is determined for the at least one of the subsets ($A_1, A_2, \dots$) based on a set of channel responses. The channel window length ($l^$) for the particular RS carrying symbol is then determined based on the corresponding hypothesis channel window length (l^*).



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METHOD AND RECEIVING NODE FOR DETERMINING A CHANNEL WINDOW LENGTH

Technical field

The present disclosure relates generally to a method and a receiving node, for
5 determining a channel window length L^A for a transformed domain channel estimator.

Background

In the field of wireless communication, channel estimation is often performed in a receiving node based on known reference signals received in symbols, herein
10 referred to as RS symbols, e.g. at regular intervals. When operating in a wireless network, channel estimation in the receiving node generally enables improved detection of received radio signals which are more or less contaminated by various noise and interference from other transmissions. If efficient channel estimation is accomplished, higher data rates can be used in the communication and the
15 capacity of the network can be improved, even when the radio conditions are poor and/or the relative speed between transmitter and receiver is high.

This disclosure may be applied to a wireless network where signals are communicated using Orthogonal Frequency-Division Multiplexing, OFDM. For example, the wireless network may be operating according to Long Term
20 Evolution (LTE) or according to 5G, also referred to as “New Radio” (NR), both being defined by the third Generation Partnership Project, 3GPP. The term “receiving node” used herein may refer to a wireless device, sometimes denoted User Equipment (UE), or to a network node which may be denoted base station, eNB or gNB, depending on the terminology used. The present disclosure is not
25 limited to any particular types of receiving node.

The physical layer of NR is expected to handle many different transmission scenarios by supporting multiple transmission numerologies, variable data transmission time intervals and early decoding for latency critical applications. These transmission scenarios impose a need for the physical layer to be even
30 more flexible than LTE.

Similar to LTE, NR will adopt OFDM based waveforms with physical layer channels (control and data) and reference signals mapped on radio resources organized in a time-frequency resource grid. Different forms of reference signals exist in the NR physical layer for reliable estimation of channel features which
5 serve diverse purposes, for instance, demodulation reference signals (DMRS), sounding reference signals (SRS), channel state information reference signals (CSI-RS), phase tracking reference signals (PTRS), and tracking reference signals (TRS).

However, it may sometimes be a drawback that the channel estimation performed
10 by a receiving node in a wireless network is not accurate enough to provide good and desirable performance and/or capacity in the network.

Summary

It is an object of embodiments described herein to address at least some of the problems and issues outlined above. It is possible to achieve this object and
15 others by using a method and a receiving node as defined in the attached independent claims.

According to one aspect, a method is performed by a receiving node for determining a channel window length for a transformed domain channel estimator, the channel window length to be applied for a particular reference signal, RS,
20 carrying symbol. In this method, the receiving node obtains at least two subsets of RS carrying symbols out of a set of RS carrying symbols received at the receiving node, the particular RS carrying symbol being comprised in at least one of the at least two subsets of RS carrying symbols.

The receiving node further determines, for the at least one of the at least two
25 subsets of RS carrying symbols, a corresponding hypothesis channel window length based on a set of channel responses, each channel response in said set of channel responses corresponding to a respective RS carrying symbol of said at least one of the at least two subsets of RS carrying symbols.

The receiving node then determines the channel window length for the particular RS carrying symbol comprised in the at least one of the at least two subsets of RS carrying symbols based on the determined corresponding hypothesis channel window length.

- 5 According to another aspect, a receiving node is arranged to determine a channel window length for a transformed domain channel estimator, the channel window length to be applied for a particular reference signal, RS, carrying symbol. The receiving node is configured to obtain at least two subsets of RS carrying symbols out of a set of RS carrying symbols received at the receiving node, the particular
- 10 RS carrying symbol being comprised in at least one of the at least two subsets of RS carrying symbols.

- The receiving node is further configured to determine, for the at least one of the at least two subsets of RS carrying symbols, a corresponding hypothesis channel window length based on a set of channel responses, each channel response in
- 15 said set of channel responses corresponding to a respective RS carrying symbol of said at least one of the at least two subsets of RS carrying symbols.

- The receiving node is also configured to determine the channel window length for the particular RS carrying symbol comprised in the at least one of the at least two subsets of RS carrying symbols based on the determined corresponding
- 20 hypothesis channel window length.

When using either of the above method and receiving node, it is an advantage that channel estimation can be made faster and more accurate and reliable than when using conventional techniques, and without adding too much complexity.

- The above method and receiving node may be configured and implemented
- 25 according to different optional embodiments to accomplish further features and benefits, to be described below.

A computer program is also provided comprising instructions which, when executed on at least one processor in the above receiving node, cause the at least one processor to carry out the method described above. A carrier is also provided

which contains the above computer program, wherein the carrier is one of an electronic signal, an optical signal, a radio signal, or a computer readable storage medium.

Brief description of drawings

- 5 The solution will now be described in more detail by means of illustrative examples and with reference to the accompanying drawings, in which:

Fig. 1 is a communication scenario involving a receiving node and a transmitting node, where the solution may be used in the receiving node.

- 10 Figs 2A-D illustrate some examples of how reference signals may be transmitted in different patterns of RS symbols according to NR.

Fig. 3 is a schematic block diagram illustrating a procedure for channel estimation in a receiving node, where the solution may be utilized.

Fig. 4 is a flow chart illustrating a procedure in a receiving node, according to some examples.

- 15 Fig. 5 is another flow chart illustrating how the receiving node may perform parts of the procedure in Fig. 4, according to further examples.

Fig. 6 illustrates how the noisy Channel Impulse Response (CIR) of samples taken in either of three symbols may fluctuate over time, which may be utilized in the procedures herein.

- 20 Fig. 7 is a logic diagram illustrating a procedure in a receiving node for finding an accurate channel window length for three RS symbols, where the solution may be utilized.

Fig. 8 is a block diagram illustrating how a receiving node may be structured, according to further examples.

- 25 Fig. 9 is a diagram illustrating how the solution may be used when RS symbols are communicated on different frequencies, according to further examples.

Fig. 10 is a diagram illustrating how RS symbols may be communicated in two different blocks of subcarriers, according to further examples.

Detailed description

Briefly described, a solution is provided to improve the performance of channel estimation as compared to conventional channel estimation techniques. In this solution, it has been realized that the performance and accuracy of channel estimation is largely dependent of how well a channel window length used for taking samples in a Reference Signal (RS) symbol is covering the wanted channel taps and does not cover parts with noise only. Therefore, it is beneficial if the channel window length is not too large so that parts with noise only are sampled, nor too small so that any useful channel taps are missed and not sampled.

A high performance of channel estimation can be achieved by finding an accurate channel window length for an RS symbol so that useful samples of the signal can be taken within the channel window length of said RS symbol. The samples taken within that channel window length are then used as a basis for performing channel estimation. It will be described below how such an accurate channel window length can be determined according to some embodiments and examples.

Fig. 1 illustrates schematically a communication scenario where the solution may be used when a receiving node 100 receives signals 104 transmitted from a transmitting node 102. This figure illustrates a basic operation of the receiving node 100 as follows. The receiving node 100 continuously performs channel estimation 100A on reference signals from the transmitting node 102 and uses the estimated channel as input for signal detection 100B on any other signals from the transmitting node 102 carrying control and data. This figure will be used as a reference when describing various examples and features below. The receiving node 100 may alternatively be denoted a communication node or a radio node, which alternative terms could be used throughout the description instead of receiving node or radio receiving node.

The solution will be described and explained herein in terms of functionality in a receiving node which is operable to perform channel estimation based on received

reference signals, and also to determine a channel window length for a transformed domain channel estimator. The determined channel window length to be used for the channel estimation is generally denoted $L^{\wedge}$ herein.

The term “receiving node” used throughout this disclosure can be understood as a logical entity that may be realized in one or more physical nodes such as a wireless device or a network node that is capable of receiving and processing received radio signals and of performing channel estimation based on such received signals.

First, some techniques and features for performing channel estimation based on received reference signals will be discussed.

It was mentioned above that known reference signals may be received in RS symbols at regular and thus predictable intervals. In NR for example, multiple DMRS patterns are defined which can be signaled by control information to wireless devices. One reason of using multiple DMRS patterns in NR is to meet the need of various channel conditions and use cases, e.g., various mobility, SNR, payload, and decoding latency.

Some examples of how reference signals may be transmitted in different patterns of symbols containing the RS according to NR, are illustrated Figs 2A-D, where the RS symbols are comprised in a resource block having a time – frequency grid of 14 symbols 0-13 distributed in the time domain and 12 subcarriers distributed in the frequency domain. The RSs may be DMRSs as indicated in the figures, although other RSs could also be employed in the illustrated manner.

Four different RS patterns are illustrated in these examples as follows.

In **Fig. 2A**, RSs occur in every second subcarrier in symbol 2. This pattern is categorized as a single-symbol front loaded pattern.

In **Fig. 2B**, RSs occur in every second subcarrier in symbols 2 and 3. This pattern is categorized as a double-symbol front loaded pattern.

In **Fig. 2C**, RSs occur in every second subcarrier in symbols 2 and 11, and so-called “extra RSs” also occur in every second subcarrier in symbols 3 and 10. This pattern is categorized as a front loaded and back loaded pattern.

In **Fig. 2D**, RSs occur in every second subcarrier in symbols 2, 7 and 11. This pattern is categorized as a multiple (>2 symbols) distributed pattern.

NR supports both frequency-division-multiplexed (FDM) and code-division-multiplexed (CDM) RS ports on the same OFDM symbol for multi-layer/UE transmissions. Accurate and reliable estimation of channel features in various transmission scenarios is critical for NR performance, since the channel estimation performance impacts the sequential signal processing units.

In a transmission of the NR system, the DMRS patterns in the physical layer are expected to be dynamically or semi-statically configured. Therefore, an efficient channel estimator needs to be adaptive, in order to utilize all the information that is available in the different patterns, and at the same time with low complexity.

There are mainly two types of channel estimator solutions used in practice for OFDM system:

1. Wiener filter in the frequency domain, and
2. Filter in some transformed domain.

Usually, the wiener filter in the frequency domain needs a reliable channel analyzer which is typically operated on the transformed domain, in order to set up the filter shape and provide input parameters such as noise variance to the channel estimation. It can be assumed that the second solution will often be implemented in practice.

Channel estimation on the transformed domain comprises identifying a valid number of channel taps from the noisy samples. Considering N noisy samples in the transformed domain, the actual channel is only contained in L samples, where L is less than N , whereas the remaining $N-L$ samples contain only noise and

interference. In typical broadband transmissions, the N samples, also referred to as the N -length sample vector, are sparse in the transform domain, i.e., $L \ll N$, meaning that the number of taps is much smaller than the number of available samples.

- 5 The channel estimator computes a window length $\hat{L}$, such that the first $\hat{L}$ taps/samples are kept, and outside this window the samples are assumed to be noise and/or interference and will therefore not be used. Selecting a fitting window length that is neither too short nor too long, is a significant operation of the channel estimator. The criterion to be used for window length selection, can basically be
- 10 casted in two categories:
1. Linear selection methods that choose $\hat{L}$ to be proportional to the length of the input noisy samples, i.e., a fraction $x\%$ of the samples is maintained where the value of x can be freely chosen.
 2. Adaptive methods which compute $\hat{L}$ using some function to identify channel
- 15 taps from the pure noise samples based on obtained/estimated statistics.

In order to obtain accurate and reliable channel estimation for various use-cases, the aforementioned window selection methods encounter some limitations. First, the linear selection cannot cope with time-varying transmission scenarios, since

20 the choice of x is usually tailored for a range of specific types of transmission. For example, proportional selection may be too conservative for a highly dispersive channel, i.e., too few samples may be kept relative to the actual number of channel taps when x is small. The opposite can also be true so that the proportional selection may be too aggressive keeping too much noise by retaining

25 a high fraction of the input N -length vector.

Second, for the narrow-band transmission or for the transmission which uses a large number of orthogonal RS ports, the channel taps may be largely dispersive inside the transformed domain which impairs the orthogonality across DMRS

ports. In this scenario, commonly referred to as a pilot contamination scenario, the adaptive methods encounter difficulties determining the useful statistics, therefore render unstable window length estimation. Moreover, in the low SNR region, where the desired channel taps are dominated by noise, adaptive methods cannot easily identify where the channel taps are located.

For time varying channels, channel estimation on the physical channel is typically carried out by interpolation of the estimates from multiple distributed DMRS symbols. If the channel estimation on each of the DMRS symbols are not reliable, the interpolation performance in the time domain is foreseen to be unstable. For tough channel conditions, e.g., high mobility, low SNR, small allocation, it is usually a challenge to provide reliable channel estimation due to the reasons above.

In **Fig. 3**, it is illustrated how a channel estimator operates based on the above-mentioned transformed domain filter solution. First, matched filter estimates of received samples are obtained in the frequency domain, in an **operation 300**. The obtained estimates are subjected to a Discrete Cosine Transform, DCT, in a next **operation 302**. The window length is determined in a further **operation 304**. The samples falling within the window are then subjected to an Inverse Discrete Cosine Transform, IDCT, in a next **operation 306**. Finally, the transformed and filtered samples are provided as channel estimates in the frequency domain, in an **operation 308**.

In this disclosure, an adaptive window selection procedure for the transformed domain channel estimator will be described. This procedure can be useful in a scenario where multiple RS symbols are available that can be used in the time domain. The following two operations may be employed:

1. Given the available RS in multiple symbols, determine two or more subsets of RSs that can be used jointly for window estimation. Each element in a determined subset corresponds to a RS symbol. The channels in the RS symbols within each subset can be considered to be correlated, and the channels in the RS symbols across two subsets can be considered independent of each other.
2. Perform joint window length estimation based on the determined subsets, which may include the following sub-operations:
 - a. Based on all the available RS symbols (regardless of which subset they belong to), estimate noise statistics, e.g. mean and variance.
 - b. In each subset, apply the joint estimation on the window length based on the estimated noise statistics.
 - c. Make a final decision of the window length estimation on each of the RS symbols, based on the estimation from all subsets.

An example of how the solution may be employed in terms of actions performed by a receiving node, such as the receiving node 100 in Fig. 1, is illustrated by the flow chart in **Fig. 4** which will now be described with further reference to Fig. 1, although this procedure is not limited to the example of Fig. 1. Fig. 4 thus

illustrates a method or procedure in the receiving node 100 for determining a channel window length L^* for a transformed domain channel estimator, the channel window length L^* to be applied for a particular reference signal (RS) carrying symbol. Some optional example embodiments that could be used in this procedure will also be described. Throughout this disclosure, the term RS carrying symbols could be replaced by "RS symbols" for short.

A first **action 400** illustrates that the receiving node 100 obtains at least two subsets $A_1, A_2, \dots$ of RS carrying symbols out of a set of RS carrying symbols $\{S_1, S_2, \dots\}$ received at the receiving node 100, the particular RS carrying symbol being

comprised in at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols.

In another **action 402**, the receiving node 100 may estimate noise statistics related to at least one of noise mean and noise variance for the RS carrying symbols in the received set of RS carrying symbols $\{S_1, S_2, \dots\}$. The estimated noise statistics can then be used for calculating the likelihood of a number of hypothesis channel window lengths. For example, it may be used for calculating the likelihood of each hypothesis channel window length l in the set of hypothesis channel window lengths.

10 In another **action 404**, the receiving node 100 determines, for the at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols, a corresponding hypothesis channel window length l^* based on a set of channel responses. Throughout this disclosure, the term channel response could be replaced by the more descriptive term "channel impulse response". Each channel response or
15 channel impulse response in said set of channel responses corresponds to a respective RS carrying symbol of said at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols.

In a further **action 406**, the receiving node 100 determines the channel window length $l^\wedge$ for the particular RS carrying symbol, or particular RS symbol for short,
20 comprised in the at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols, based on the corresponding hypothesis channel window length l^* determined in action 404.

Some further examples of embodiments that may be employed in the above procedure in Fig. 3 will now be described. In one example embodiment, the
25 receiving node 100 may further perform channel estimation for the particular RS carrying symbol based on L samples in the frequency domain taken in the particular RS carrying symbol within the determined channel window length $l^\wedge$, as illustrated by another **action 408**.

In another example embodiment, determining the corresponding hypothesis channel window length l^* for the at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols in action 404 may be performed by executing the following two operations:

- 5 1) calculating a likelihood of each hypothesis channel window length l in a set of hypothesis channel window lengths based on samples, taken in the RS carrying symbols comprised in the at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols, within the respective hypothesis channel window length l , and
- 10 2) selecting, as the corresponding hypothesis channel window length (l^*) for the at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols, the hypothesis channel window length with highest likelihood, out of the set of hypothesis channel window lengths.

In another example embodiment, the likelihood of each hypothesis channel window length l in the set of hypothesis channel window lengths may be calculated as $P(l) = f(y(S_1), y(S_2), \dots, l)$, where $y(S_1), y(S_2), \dots$ denote sample sequences taken in respective RS carrying symbols $S_1, S_2, \dots$ for the hypothesis channel window length (l) and $f(y(S_1), y(S_2), \dots, l)$ denotes a likelihood function based on the RS carrying symbols, out of the set of RS carrying symbols $\{S_1, S_2, \dots\}$, comprised in the at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols.

In another example embodiment, when the foregoing embodiment is employed, the likelihood function $f(y(S_1), y(S_2), \dots, l)$ may in one alternative be calculated by first calculating an average sample sequence as $y(S_1, S_2, \dots, S_n) = 1/n [y(S_1) + y(S_2) + \dots + y(S_n)]$, and then calculating the likelihood $f(y(S_1), y(S_2), \dots, y(S_n), l)$ of the hypothesis channel window length (l) based on the average sample sequence $y(S_1, S_2, \dots, S_n)$.

In another example embodiment, the likelihood function $f(y(S_1), y(S_2), \dots, l)$ may in another alternative be calculated by first calculating a log-likelihood of the hypothesis channel window length (l) for each RS symbol separately as $f(y(S_1), l)$,

$f(y(S_2), l) \dots f(y(S_n), l)$, respectively, and then calculating a joint likelihood of the hypothesis channel window length (l) as $f(y(S_1), y(S_2) \dots y(S_n), l) = f(y(S_1), l) + f(y(S_2), l) + \dots f(y(S_n), l)$.

In another example embodiment, the particular RS carrying symbol may be
5 comprised in more than one of the obtained at least two subsets $A_1, A_2, \dots$ of RS carrying symbols, and in that case the channel window length l^* for said particular RS carrying symbol may be determined as an average of respective corresponding hypothesis channel window lengths l^* determined for each of the more than one of the obtained at least two subsets $A_1, A_2, \dots$ of RS carrying
10 symbols.

In another example embodiment, noise statistics related to at least one of noise mean and noise variance may be estimated, as shown in action 402, for the RS carrying symbols in the received set of RS carrying symbols $\{S_1, S_2, \dots\}$, and the estimated noise statistics could in that case be used for calculating the likelihood
15 of each hypothesis channel window length l in the set of hypothesis channel window lengths.

In further example embodiments, when the foregoing embodiment is employed, the noise statistics may be estimated using averaging over samples within a hypothesis noise window for RS carrying symbols in two or more of said obtained
20 at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols, or by estimating the noise mean and/or noise variance in each of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols over samples within the hypothesis noise window on each received RS carrying symbol in the respective one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols.

25 In another example embodiment, the separation of RS carrying symbols in each one of the obtained at least two subsets $A_1, A_2, \dots$ of RS carrying symbols does not exceed a certain specified number of symbols d . The number of symbols d is limited by the largest distance between two RS carrying symbols in the received set of RS carrying symbols $\{S_1, S_2, \dots\}$. In NR, this number is limited to $d \leq 12$
30 (e.g., the first symbol number 0, and the last symbol number 13, i.e. the number of

symbols is 14). The subsets $A_1, A_2, \dots$ of RS carrying symbols may be formed so that the number of symbols d in one or more, or in each one, of the subsets $A_1, A_2, \dots$ of RS carrying symbols is less than the largest distance between two RS carrying symbols in the received set of RS carrying symbols $\{S_1, S_2, \dots\}$.

- 5 In further example embodiments, when the foregoing embodiment is employed, the specified number of symbols d is based on at least one of: slot format of the RS, carrier frequency of the RS, a subcarrier spacing used for transmission of the RS, relative speed between the receiving node 100 and a transmitting node 102, and a precoder applied to the RS.
- 10 In another example embodiment, said determination of the channel window length L^* may be performed in a transformed domain achieved by Fast Fourier Transform (FFT) or Discrete Cosine Transform (DCT), or any other invertible transform.

In another example embodiment, the RS carrying symbols may be Orthogonal Frequency-Division Multiplexing, OFDM, symbols.

- 15 The above method or procedure could also be described as follows, with further reference to Fig. 1.

The method is performed by a receiving node 100 for determining a channel window length L^* for a transformed domain channel estimator, the channel window length L^* to be applied for a particular reference signal (RS) carrying symbol. In this method, the receiving node 100 performs the following actions A-D:

- 20 A) Obtaining at least two subsets $A_1, A_2, \dots$ of RS carrying symbols out of a set of RS carrying symbols $\{S_1, S_2, \dots\}$ received at the receiving node 100, the first RS carrying symbol being comprised in at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols. The at least two subsets $A_1, A_2, \dots$ of RS carrying symbols may comprise a first subset A_1 and a second subset A_2 of RS carrying symbols out of the set of RS carrying symbols $\{S_1, S_2, \dots\}$. The particular RS carrying symbol may be comprised in at least one of the first and second subsets A_1, A_2 of RS carrying symbols. In some examples, the particular RS carrying
- 25

symbol may be comprised in each one of the first and second subsets A_1 , A_2 of RS carrying symbols.

B) Determining, for the at least one of the at least two subsets A_1 , A_2 , ... of RS carrying symbols, a corresponding hypothesis channel window length l^* based on a set of channel responses, each channel response in said set of channel responses corresponding to a respective RS carrying symbol of said at least one of the at least two subsets A_1 , A_2 , ... of RS carrying symbols. The corresponding hypothesis channel window length l^* is a hypothesis channel window length that corresponds to the at least one of the at least two subsets A_1 , A_2 , ... of RS carrying symbols in that it is determined based on a set of channel responses where each channel response in the set of channel responses corresponds to a respective RS carrying symbol of the at least one of the at least two subsets A_1 , A_2 , ... of RS carrying symbols. Each channel response in the set of channel responses may be determined from N respective samples in the frequency domain taken in a respective RS carrying symbol of the at least one of the at least two subsets A_1 , A_2 , ... of RS carrying symbols.

C) Determining the corresponding hypothesis channel window length l^* for the at least one of the at least two subsets A_1 , A_2 , ... of RS carrying symbols may comprise determining at least one of a corresponding first hypothesis channel window length l_1^* for the first subset A_1 of RS carrying symbols and a corresponding second hypothesis channel window length l_2^* for the second subset A_2 of RS carrying symbols. In some examples, e. g. when the particular RS carrying symbol is comprised in each one of the first and second subsets A_1 , A_2 of RS carrying symbols, determining at least one of a corresponding first hypothesis channel window length l_1^* for the first subset A_1 of RS carrying symbols and a corresponding second hypothesis channel window length l_2^* for the second subset A_2 of RS carrying symbols may comprise determining, for the first and second subsets A_1 , A_2 of RS carrying symbols, the corresponding first and second hypothesis channel window lengths l_1^* , l_2^* . The corresponding first and second hypothesis channel window lengths l_1^* , l_2^* may be determined based on first and second sets of channel responses respectively. The corresponding first and

second hypothesis channel window lengths l_1^* , l_2^* are hypothesis channel window lengths that correspond to the first and second subsets A_1 , A_2 of RS carrying symbols respectively in that the corresponding first hypothesis channel window length l_1^* is determined based on the first set of channel responses, where each
5 channel response in the first set of channel responses corresponds to a respective RS carrying symbol of the first subset A_1 of RS carrying symbols, and the corresponding second hypothesis channel window length l_2^* is determined based on the second set of channel responses, where each channel response in the second set of channel responses corresponds to a respective RS carrying symbol
10 of the second subset A_2 of RS carrying symbols. Each channel response in the first and second sets of channel responses may be determined from N respective samples in the frequency domain taken in a respective RS carrying symbol of said first and second subsets A_1 , A_2 of RS carrying symbols respectively.

D) Determining the channel window length l^* for the particular RS carrying symbol
15 comprised in the at least one of the at least two subsets A_1 , A_2 , ... of RS carrying symbols based on the determined corresponding hypothesis channel window length l^* . The at least one of the at least two subsets A_1 , A_2 , ... of RS carrying symbols may be at least one of the first and second subsets A_1 , A_2 of RS carrying symbols and the determined corresponding hypothesis channel window length l^*
20 may be at least one of the corresponding first and second hypothesis channel window lengths l_1^* , l_2^* for the at least of the first and second subsets A_1 , A_2 of RS carrying symbols respectively. In some examples, e. g. when the particular RS carrying symbol is comprised in each one of the first and second subsets A_1 , A_2 of RS carrying symbols, the at least one of the at least two subsets A_1 , A_2 , ... of RS
25 carrying symbols may comprise the first and second subsets A_1 , A_2 of RS carrying symbols and the determined corresponding hypothesis channel window length l^* may comprise the corresponding first and second hypothesis channel window lengths l_1^* , l_2^* for the first and second subsets A_1 , A_2 of RS carrying symbols respectively. In this case the channel window length l^* for the particular RS
30 carrying symbol comprised in each of the first and the second subsets A_1 , A_2 of RS carrying symbols is thus determined based on the determined corresponding first

and second hypothesis channel window lengths l_1^* , l_2^* for the first and second subsets A_1 , A_2 of RS carrying symbols.

Fig. 5 illustrates another example of a procedure that could be performed by the receiving node 100 for determining a suitable channel window length to be applied in channel estimation. In this example, a number of hypothesis channel window lengths are tested to identify which hypothesis is likely to be the best basis for channel estimation. It is assumed that the receiving node 100 has obtained at least two subsets A_1 , A_2 , ... of RS carrying symbols in the manner described for action 400 above.

- 10 In a first **action 500**, the receiving node 100 obtains or selects a set of hypothesis channel window lengths to be tested for each subset of RS carrying symbols. In a next **action 502**, the receiving node 100 estimates noise statistics for each RS symbol in the sets and uses the noise statistics to suppress the noise on samples taken in the obtained RS symbols.
- 15 In a next **action 504**, the receiving node 100 calculates a likelihood of each hypothesis channel window length based on the RS symbols in each subset received within the respective hypothesis channel window. Thereby, the receiving node 100 is able to select, in an **action 506**, the hypothesis channel window length that has the highest likelihood as calculated in action 504, for use in the
- 20 channel estimation. The actions 500-506 can be repeated for multiple successive subsets of obtained RS carrying symbols.

- In **Fig. 6**, an example of how two subsets A_1 , A_2 of RS carrying symbols could be employed in the embodiments herein, is illustrated. In this figure, a resource block of the above-mentioned multiple distributed pattern is shown where the RS
- 25 carrying symbols denoted S_1 , S_2 and S_3 occur in symbols 2, 7 and 11, respectively, as also shown in Fig. 2D. The first subset A_1 of RS carrying symbols includes the RSs S_1 and S_2 while the second subset A_2 of RS carrying symbols includes the RSs S_2 and S_3 . Hence, the RSs S_2 are included in both subsets A_1 , A_2 . The diagram shown below the resource block illustrates how a channel
- 30 impulse response (CIR) varies over a succession of samples taken during an RS

carrying symbol. It can be seen that a first part of the symbol has a good channel response while a second part of the symbol is mainly dominated by noise. The optimal channel window length to be used for channel estimation would in this case be in the first part of the symbol with good channel impulse response.

- 5 An example of how at least some of the embodiments herein could be employed in practice, will now be described.

In this example, the solution is applied to a transmission using a single port DMRS. Further, joint estimation in the time domain is also employed and a multiple symbol DMRS pattern is also employed. A generalization for multi-port channel
 10 estimation can be made by changing the dimension of inputs. Below, a hypothesis channel window is referred to as a hypothesis for short.

Considering a regular slot transmission, the DMRS symbols are indexed by symbol indices, e.g., $\{S_1, S_2, S_3\}$ where $S_i \in [0:13]$. An algorithm with operations 1-6, also illustrated in **Fig. 7**, can be employed as follows:

- 15 1. Determine a sequence of subsets based on the available DMRS symbols, such that the symbol indices in the same subset have mutual distance smaller than d . d is a parameter which varies depending on the scenario.

Based on the agreed patterns for DMRS, a reasonable value to initialize d , in a regular transmission slot, would be $d = 7$. The determined subsets of

- 20 RS carrying symbols are for example:

$A_1 = \{S_1, S_2\}$, $A_2 = \{S_2, S_3\}$ such that the condition $|S_i - S_j| < d$ holds when the symbols belong to the same subset. A_1 and A_2 thus forms a sequence of subsets of RS carrying symbols which is illustrated at 700, 702 in Fig. 7, which also corresponds to the example in Fig. 6.

- 25 2. Hypothesis: Assume that in the transformed domain, which is obtained based on a single DMRS symbol, channel taps exist in the index window $[0: L]$, and only noise samples exist in the window $[L+1, N]$, where N is the

transform size. The window $[0: L]$ is assumed to be the same for all RS symbols.

3. Perform noise level estimation based on the current hypothesis. Depending on the transmission scenarios, the noise estimation may be carried out in either intra- or inter-subset fashion. In the later part of this section, the detailed implementations of this operation are described.

4. Hypotheses testing in each subset, given the estimated noise statistics from operation 3 above. Taking $A_1 = \{S_1, S_2\}$ as an example, for the hypotheses $[0: L]$, calculate the likelihood of the current hypothesis based on both of the

RS symbols:

$$P(I) \triangleq f(S_1, S_2)$$

$f(S_1, S_2)$ denotes a likelihood function based on $\{S_1, S_2\}$. Depending on implementations, the likelihood function may have various forms.

The estimate of the window length L^* corresponds to the hypothesis channel window with maximum likelihood. This can be expressed mathematically as follows:

$$L^* = \underset{L \in \{0: M\}}{\operatorname{argmax}} P(L).$$

It should be noted that L^* corresponds to the same channel length for both DMRS symbols S_1 and S_2 .

5. Repeat operation 4 for all subsets A_i to obtain the window length on each DMRS symbol. Operations 2-5 are basically represented at 704 in Fig. 7.
6. If multiple estimates on the same symbol are carried out in the operations 4 and 5, the final decision on this symbol depends on those multiple estimates. For instance, for the window length on DMRS symbol S_2 , two

estimates are produced based on A_1 and A_2 , denoted as $I^*(A_1)$ and $I^*(A_2)$, respectively. The final estimate I^* can be determined as an average: $I^* = \frac{1}{2}(I^*(A_1) + I^*(A_2))$. This operation is basically represented at 706 in Fig. 7.

5

It can be noted that the embodiments and examples herein are fundamentally different compared with algorithms that average multiple single-shot window selection, because the effective Signal-to-Noise Ratio (SNR) improvement by noise suppression is carried out even before the hypothesis testing.

10 In operation 3 above, the noise statistics estimation may be carried out in two major alternative implementations:

1. Inter-subset noise estimation: The noise mean and noise variance estimation are averaged over the hypothesis noise window $[L+1, N]$ from in two or more subsets ($A_1, A_2, \dots$) of RS carrying symbols or from all RS symbols $\{S_1, S_2, S_3\}$.

15

2. Intra-subset noise estimation: For each subset, the noise mean and variance are estimated based on the hypothesis noise window $[L+1, N]$ from the RS symbol(s) in the current subset.

20 The choice of inter- and intra-subset noise estimation is a receiver decision based on, for example:

- If currently the transmission is in Multi-User (MU)- Multiple Input Multiple Output (MIMO) or Single-User (SU)-MIMO mode, which is informed dynamically by the control information via antenna port mapping in NR.
- 25 • If strong interference on the RS positions is detected, or the interfering ports are signaled via antenna port or other control information.

- If the interfering RS have the same footprint in the resource grid as the desired RS. This is detected by the receiver enabled with the functionality.

The decision in operation 3 above is made by the receiver in order to collect the RS symbols with similar noise feature together for estimation.

In operation 4 above, the calculation of $f(S_1, S_2)$ may contain two alternative implementations 1 and 2 below:

1. Average the noisy samples over two RS symbols and calculate the likelihood afterwards. For instance, let $y(S_1), y(S_2)$ be two noisy sample sequences in the transformed domain, based on RS symbols S_1, S_2 , respectively. Apply the sum and average:

$$y(S_1, S_2) \stackrel{\text{def}}{=} \frac{1}{2} [y(S_1) + y(S_2)]$$

Calculate the likelihood $f(S_1, S_2)$, based on the new samples $y(S_1, S_2)$.

2. Calculate the likelihood of the hypothesis on each of the sequences and combine them coherently afterwards. For instance, let $f(S_1)$ and $f(S_2)$ represent the log-likelihood of the hypothesis based on DMRS symbol S_1 and S_2 , respectively. The joint likelihood is $f(S_1, S_2) = f(S_1) + f(S_2)$.

In a possible implementation, the input parameter d used for determining the subset of RS symbols can be chosen based on slot-format and carrier frequency.

In another possible implementation, the value of d can be chosen based on a correlation threshold ρ_t . For example, d may be selected to group RS sequences S_k and S_j such that correlation $(S_k S_j) > \rho_t$. The eNB/gNB can then compute the

correlation of the group's sequences, based on the channel estimates, in order to perform new grouping.

In another possible implementation, d can be dynamically adapted as a function of the UE speed (or equivalently Doppler spread). For instance, if the UE and the propagation environment is (almost) static then the value of d can be increased.

In another possible implementation, d may depend on a precoder applied in the RS such that the RS using the same precoder can be jointly exploited.

In another possible implementation, the actual likelihood calculation of the window length hypothesis may be based on a certain model selection criterion, which regularizes the likelihood with a penalty on model order. These criteria include Bayesian (probabilistic) approaches such as Akaike information criterion (AIC), and heuristic approaches such as analyzing the shape of the noisy sequence.

In some further implementations, pre-processing on the input sequence may be carried out to extract the principal component in a desired order. For instance, sorting the sequence may be applied before input to the algorithm in order to focus on the samples with larger magnitude.

The block diagram in **Fig. 8** illustrates a detailed but non-limiting example of how a receiving node 800 may be structured to bring about the above-described solution and embodiments thereof. In this figure, the receiving node 800 may be configured to operate according to any of the examples and embodiments of employing the solution as described herein, where appropriate. The receiving node 800 is shown to comprise a processor "P", a memory "M" and a communication circuit "C" with suitable equipment for transmitting and receiving information and messages in the manner described herein.

The communication circuit C in the receiving node 800 thus comprises equipment configured for communication using a suitable protocol for the communication depending on the implementation. The solution is however not limited to any specific types of messages or protocols.

The receiving node 800 is, e.g. by means of units, modules or the like, configured or arranged to perform at least some of the actions of the flow chart in Fig. 4 as follows.

5 The receiving node 800 is arranged to determine a channel window length $I^{\wedge}$ for a transformed domain channel estimator, the channel window length $I^{\wedge}$ to be applied for a particular reference signal RS carrying symbol.

10 The receiving node 800 is configured to obtain at least two subsets $A_1, A_2, \dots$ of RS carrying symbols out of a set of RS carrying symbols $\{S_1, S_2, \dots\}$ received at the receiving node 800, the particular RS carrying symbol being comprised in at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols. This operation may be performed by an **obtaining module 800A** in the receiving node 800, as also illustrated in action 400. The obtaining module 800A could alternatively be named a receiving module or selecting module.

15 The receiving node 800 is also configured to determine, for the at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols, a corresponding hypothesis channel window length I^* based on a set of channel responses, each channel response in said set of channel responses corresponding to a respective RS carrying symbol of said at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols. This operation may be performed by a **logic module 800B** in the receiving node 800, as also illustrated in action 404. The logic module 800B
20 could alternatively be named a determining module or computing module.

The receiving node 800 is also configured to determine the channel window length $I^{\wedge}$ for the particular RS carrying symbol comprised in the at least one of the at least two subsets $A_1, A_2, \dots$ of RS carrying symbols based on the determined
25 corresponding hypothesis channel window length I^* . This operation may be performed by the logic module 800B, as also illustrated in action 406.

The receiving node 800 may further be configured to perform channel estimation for the particular RS carrying symbol based on L samples in the frequency domain taken in the particular RS carrying symbol within the determined channel window

length L^A . This operation may be performed by an **estimating module 800C** in the receiving node 800, as also illustrated in action 408. The estimating module 800C could alternatively be named a channel estimator or similar.

It should be noted that Fig. 8 illustrates various functional modules in the receiving node 800 and the skilled person is able to implement these functional modules in practice using suitable software and hardware equipment. Thus, the solution is generally not limited to the shown structure of the receiving node 800, and the functional modules therein may be configured to operate according to any of the features, examples and embodiments described in this disclosure, where appropriate.

The functional modules 800A-C described above may be implemented in the receiving node 800 by means of program modules of a computer program comprising code means which, when run by the processor P causes the receiving node 800 to perform the above-described actions and procedures. The processor P may comprise a single Central Processing Unit (CPU), or could comprise two or more processing units. For example, the processor P may include a general purpose microprocessor, an instruction set processor and/or related chips sets and/or a special purpose microprocessor such as an Application Specific Integrated Circuit (ASIC). The processor P may also comprise a storage for caching purposes.

The computer program may be carried by a computer program product in the receiving node 800 in the form of a memory having a computer readable medium and being connected to the processor P. The computer program product or memory M in the receiving node 800 thus comprises a computer readable medium on which the computer program is stored e.g. in the form of computer program modules or the like. For example, the memory M may be a flash memory, a Random-Access Memory (RAM), a Read-Only Memory (ROM) or an Electrically Erasable Programmable ROM (EEPROM), and the program modules could in alternative embodiments be distributed on different computer program products in the form of memories within the receiving node 800.

The solution described herein may be implemented in the receiving node 800 by a computer program comprising instructions which, when executed on at least one processor, cause the at least one processor to carry out the actions according to any of the above embodiments and examples, where appropriate. The solution
5 may also be implemented at the receiving node 800 in a carrier containing the above computer program, wherein the carrier is one of an electronic signal, optical signal, radio signal, or computer readable storage medium.

Some further details and features that may be employed will now be described.

The procedure described herein can be used to estimate the delay spread of the
10 channel used for setting up other types of channel estimators. In some implementations, the wiener filter for frequency domain channel estimator can be set up by the delay spread, and noise variance estimated from the proposed method.

In the case of a low-latency application and/or when a delay to get estimates from
15 RS within a group cannot be accepted, this solution can still be used to improve the channel estimation of later symbols. Continuing from the example above in relation to Figure 7, assume that we have a set $A_1 = \{S_1, S_2\}$. If we need early decoding then the base station can use the estimate, produced from S_1 to start decoding the first data symbols. However, for later symbols, it can estimate the channel using S_2
20 in combination with the estimate produced from S_1 .

This solution can be applied even if the RS sequences within a group A_k are located on different frequencies. As long as they correspond to the same link then the channel length, i.e., number of taps, should be the same, assuming that the underlying channel that filters the intra-group RS signals is the same as shown in
25 **Fig. 9**. This figure illustrates transmission from/to the same UE in mini-slots, over two different frequencies. Since the RS symbols are separated with a distance less than d , and the channel does not change, the RS sequences from the different resources units can be combined.

What differs is the frequency placement, which is the application of a different block $\mathbf{W}_k$ of the Fourier transform matrix. However, fundamentally the channel is the same, as can be seen in **Fig. 10**, where the channel spectrum in the different frequencies is defined by the block $\mathbf{W}_k$ that is applied on the CIR $\mathbf{h}_t$. This figure

5 illustrates blocks $\mathbf{W}_1$ and $\mathbf{W}_2$ of a Fourier transform matrix, that corresponds to assigned bandwidth. As long as $N > L$, each block can be used to recover the channel impulse response.

The channel has at most L taps, and typically it holds that $L \ll N_f$, where N_f is the size of the Discrete Fourier transform. Therefore, the same information about the
10 channel can be recovered from different chunks of the time-frequency resource grid. Therefore, combining the metrics from RS sequences, that are placed on different OFDM symbols *and* bands, should be possible.

While the solution has been described with reference to specific exemplifying embodiments, the description is generally only intended to illustrate the inventive
15 concept and should not be taken as limiting the scope of the solution. For example, the terms “receiving node”, “transmitting node”, “RS symbol”, “hypothesis channel window length”, “noise statistics” and “hypothesis noise window” have been used throughout this disclosure, although any other corresponding entities, functions, and/or parameters could also be used having the features and
20 characteristics described here. The solution is defined by the appended claims.

CLAIMS

1. A method performed by a receiving node (100) for determining a channel window length ($I^\wedge$) for a transformed domain channel estimator, the channel window length ($I^\wedge$) to be applied for a particular reference signal, RS, carrying symbol, the method comprising:
- 5 - obtaining (400) at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols out of a set of RS carrying symbols ($\{S_1, S_2, \dots\}$) received at the receiving node (100), the particular RS carrying symbol being comprised in at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols;
- 10 - determining (404), for the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols, a corresponding hypothesis channel window length (I^*) based on a set of channel responses, each channel response in said set of channel responses corresponding to a respective RS carrying symbol of said at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols; and
- 15 - determining (406) the channel window length ($I^\wedge$) for the particular RS carrying symbol comprised in the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols based on the determined corresponding hypothesis channel window length (I^*).
2. A method according to claim 1, further comprising:
- 20 - performing (408) channel estimation for the particular RS carrying symbol based on L samples in the frequency domain taken in the particular RS carrying symbol within the determined channel window length ($I^\wedge$).
3. A method according to claim 1 or 2, wherein determining the corresponding hypothesis channel window length (I^*) for the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols is performed by: 1)
- 25 calculating a likelihood of each hypothesis channel window length (I) in a set of hypothesis channel window lengths based on samples, taken in the RS carrying symbols comprised in the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS

carrying symbols, within the respective hypothesis channel window length (l), and
 2) selecting, as the corresponding hypothesis channel window length (l^*) for the at
 least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols, the
 hypothesis channel window length with highest likelihood, out of the set of
 5 hypothesis channel window lengths.

4. A method according to claim 3, wherein the likelihood of each hypothesis
 channel window length (l) in the set of hypothesis channel window lengths is
 calculated as $P(l) = f(y(S_1), y(S_2), \dots, l)$, where $y(S_1), y(S_2), \dots$ denote sample
 sequences taken in respective RS carrying symbols ($S_1, S_2, \dots$) for the hypothesis
 10 channel window length (l) and $f(y(S_1), y(S_2), \dots, l)$ denotes a likelihood function
 based on the RS carrying symbols, out of the set of RS carrying symbols ($\{S_1, S_2, \dots\}$),
 comprised in the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS
 carrying symbols.

5. A method according to claim 4, wherein the likelihood function $f(y(S_1),$
 15 $y(S_2), \dots, l)$ is calculated by first calculating an average sample sequence as $y(S_1,$
 $S_2 \dots S_n) = 1/n [y(S_1) + y(S_2) + \dots + y(S_n)]$, and then calculating the likelihood $f(y(S_1),$
 $y(S_2) \dots y(S_n), l)$ of the hypothesis channel window length (l) based on the average
 sample sequence $y(S_1, S_2 \dots S_n)$.

6. A method according to claim 4, wherein the likelihood function $f(y(S_1),$
 20 $y(S_2) \dots, l)$ is calculated by first calculating a log-likelihood of the hypothesis
 channel window length (l) for each RS symbol separately as $f(y(S_1), l), f(y(S_2), l) \dots$
 $f(y(S_n), l)$, respectively, and then calculating a joint likelihood of the hypothesis
 channel window length (l) as $f(y(S_1), y(S_2) \dots y(S_n), l) = f(y(S_1), l) + f(y(S_2), l) + \dots$
 $f(y(S_n), l)$.

25 7. A method according to any one of claims 1-6, wherein the particular RS
 carrying symbol is comprised in more than one of the obtained at least two
 subsets ($A_1, A_2, \dots$) of RS carrying symbols, and wherein the channel window
 length (l^*) for said particular RS carrying symbol is determined as an average of
 respective corresponding hypothesis channel window lengths (l^*) determined for

each of the more than one of the obtained at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols.

8. A method according to any one of claims 3-6, wherein noise statistics related to at least one of noise mean and noise variance are estimated (402, 502)

5 for the RS carrying symbols in the received set of RS carrying symbols ($\{S_1, S_2, \dots\}$), and wherein the estimated noise statistics are used for calculating the likelihood of each hypothesis channel window length (l) in the set of hypothesis channel window lengths.

9. A method according to claim 8, wherein the noise statistics are estimated

10 using averaging over samples within a hypothesis noise window for RS carrying symbols in two or more of said obtained at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols, or by estimating the noise mean and/or noise variance in each of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols over samples within the hypothesis noise window on each received RS carrying symbol in the
15 respective one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols.

10. A method according to any one of claims 1-9, wherein the separation of RS carrying symbols in each one of the obtained at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols does not exceed a specified number of symbols (d).

11. A method according to claim 10, wherein the specified number of
20 symbols (d) is based on at least one of: slot format of the RS, carrier frequency of the RS, a subcarrier spacing used for transmission of the RS, relative speed between the receiving node (100) and a transmitting node (102), and a precoder applied to the RS.

12. A method according to any one of claims 1-11, wherein the method is
25 performed in a transformed domain achieved by Fast Fourier Transform, FFT, or Discrete Cosine Transform, DCT, or any other invertible transform.

13. A method according to any one of claims 1-12, wherein the RS carrying symbols are Orthogonal Frequency-Division Multiplexing, OFDM, symbols.

14. A receiving node (800) arranged to determine a channel window length ($l^{\wedge}$) for a transformed domain channel estimator, the channel window length ($l^{\wedge}$) to be applied for a particular reference signal, RS, carrying symbol, wherein the receiving node is configured to:

- 5 - obtain at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols out of a set of RS carrying symbols ($\{S_1, S_2, \dots\}$) received at the receiving node (100), the particular RS carrying symbol being comprised in at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols,
- determine, for the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS
10 carrying symbols, a corresponding hypothesis channel window length (l^*) based on a set of channel responses, each channel response in said set of channel responses corresponding to a respective RS carrying symbol of said at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols; and
- determine the channel window length ($l^{\wedge}$) for the particular RS carrying symbol
15 comprised in the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols based on the determined corresponding hypothesis channel window length (l^*).

15. A receiving node (800) according to claim 14, wherein the receiving node is further configured to:

- 20 - perform channel estimation for the particular RS carrying symbol based on L samples in the frequency domain taken in the particular RS carrying symbol within the determined channel window length ($l^{\wedge}$).

16. A receiving node (800) according to claim 14 or 15, wherein the receiving node is configured to determine the corresponding hypothesis channel window
25 length (l^*) for the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols, by: 1) calculating a likelihood of each hypothesis channel window length (l) in a set of hypothesis channel window lengths based on samples, taken in the RS carrying symbols comprised in the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols, within the respective hypothesis channel window

length (l), and 2) selecting, as the corresponding hypothesis channel window length (l^*) for the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols, the hypothesis channel window length with highest likelihood, out of the set of hypothesis channel window lengths.

5 17. A receiving node (800) according to claim 16, wherein the receiving node is configured to calculate the likelihood of each hypothesis channel window length (l) in the set of hypothesis channel window lengths as $P(l) = f(y(S_1), y(S_2), \dots, l)$, where $y(S_1), y(S_2), \dots$ denote sample sequences taken in respective RS carrying symbols ($S_1, S_2, \dots$) for the hypothesis channel window length (l) and $f(y(S_1), y(S_2), \dots, l)$ denotes a likelihood function based on the RS carrying symbols, out of the
10 set of RS carrying symbols ($\{S_1, S_2, \dots\}$), comprised in the at least one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols.

18. A receiving node (800) according to claim 17, wherein the receiving node is configured to calculate the likelihood function $f(y(S_1), y(S_2), \dots, l)$ by first
15 calculating an average sample sequence as $y(S_1, S_2, \dots, S_n) = 1/n [y(S_1) + y(S_2) + \dots + y(S_n)]$, and then calculating the likelihood $f(y(S_1), y(S_2), \dots, y(S_n), l)$ of the hypothesis channel window length (l) based on the average sample sequence $y(S_1, S_2, \dots, S_n)$.

19. A receiving node (800) according to claim 17, wherein the receiving node
20 is configured to calculate the likelihood function $f(y(S_1), y(S_2), \dots, l)$ by first calculating a log-likelihood of the hypothesis channel window length (l) for each RS symbol separately as $f(y(S_1), l), f(y(S_2), l), \dots, f(y(S_n), l)$, respectively, and then calculating a joint likelihood of the hypothesis channel window length (l) as $f(y(S_1), y(S_2), \dots, y(S_n), l) = f(y(S_1), l) + f(y(S_2), l) + \dots + f(y(S_n), l)$.

25 20. A receiving node (800) according to any one of claims 14-19, wherein the particular RS carrying symbol is comprised in more than one of the obtained at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols, and wherein the receiving node is configured to determine the channel window length (l^*) for said particular RS carrying symbol as an average of respective corresponding hypothesis

channel window lengths (l^*) determined for each of the more than one of the obtained at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols.

21. A receiving node (800) according to any one of claims 16-19, wherein the receiving node is configured to estimate noise statistics related to at least one of noise mean and noise variance for the RS carrying symbols in the received set of RS carrying symbols ($\{S_1, S_2, \dots\}$), and to use the estimated noise statistics for calculating the likelihood of each hypothesis channel window length (l) in the set of hypothesis channel window lengths.

22. A receiving node (800) according to claim 21, wherein the receiving node is configured to estimate the noise statistics using averaging over samples within a hypothesis noise window for RS carrying symbols in two or more of said obtained at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols, or by estimating the noise mean and/or noise variance in each of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols over samples within the hypothesis noise window on each received RS carrying symbol in the respective one of the at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols.

23. A receiving node (800) according to any one of claims 14-22, wherein the separation of RS carrying symbols in each one of the obtained at least two subsets ($A_1, A_2, \dots$) of RS carrying symbols does not exceed a specified number of symbols (d).

24. A receiving node (800) according to claim 23, wherein the specified number of symbols (d) is based on at least one of: slot format of the RS, carrier frequency of the RS, a subcarrier spacing used for transmission of the RS, relative speed between the receiving node (100, 800) and a transmitting node (102), and a precoder applied to the RS.

25. A receiving node (800) according to any one of claims 14-24, wherein the receiving node is configured to determine the channel window length ($l^\wedge$) in a transformed domain achieved by Fast Fourier Transform, FFT, or Discrete Cosine Transform, DCT, or any other invertible transform.

26. A receiving node (800) according to any one of claims 14-25, wherein the RS carrying symbols are Orthogonal Frequency-Division Multiplexing, OFDM, symbols.

27. A computer program comprising instructions which, when executed on at
5 least one processor, cause the at least one processor to carry out the method according to any one of claims 1-13.

28. A carrier containing the computer program of claim 27, wherein the carrier is one of an electronic signal, optical signal, radio signal, or computer readable storage medium.

1/7

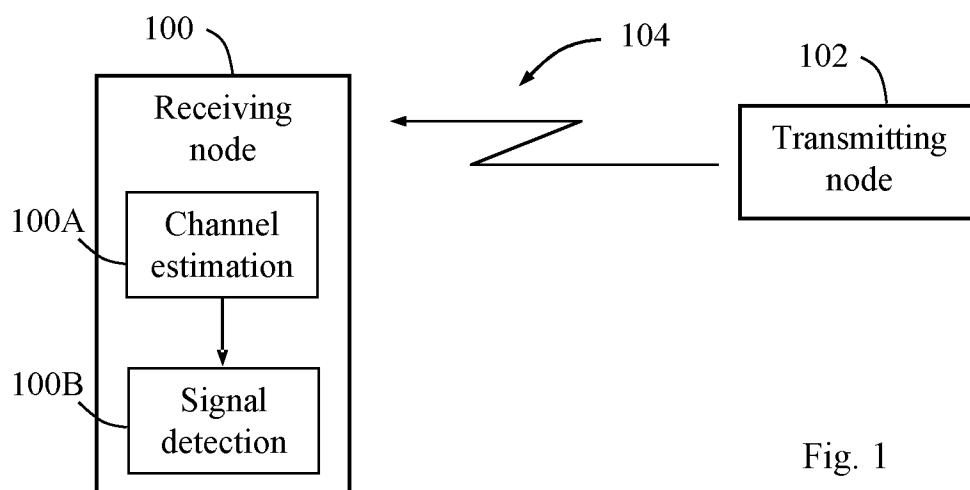


Fig. 1

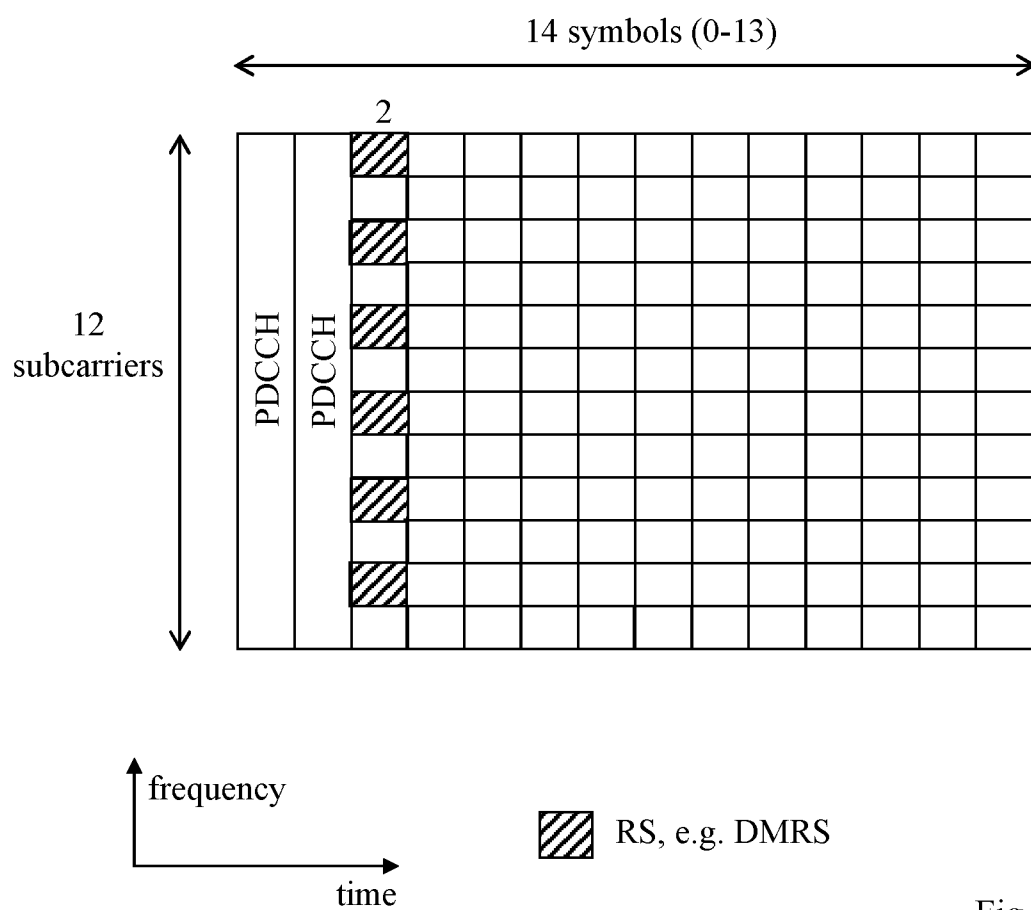


Fig. 2A

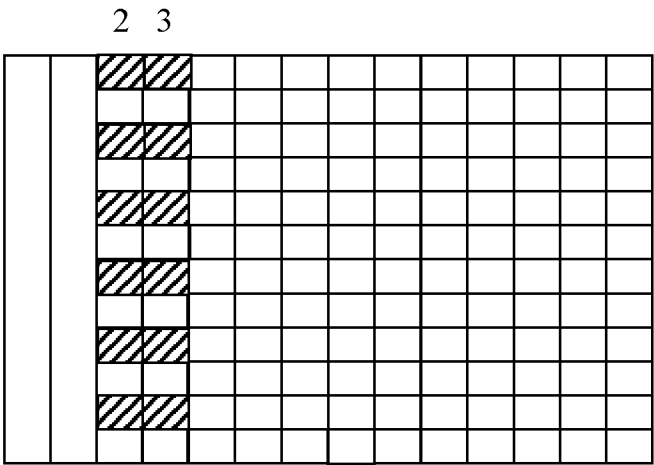


Fig. 2B

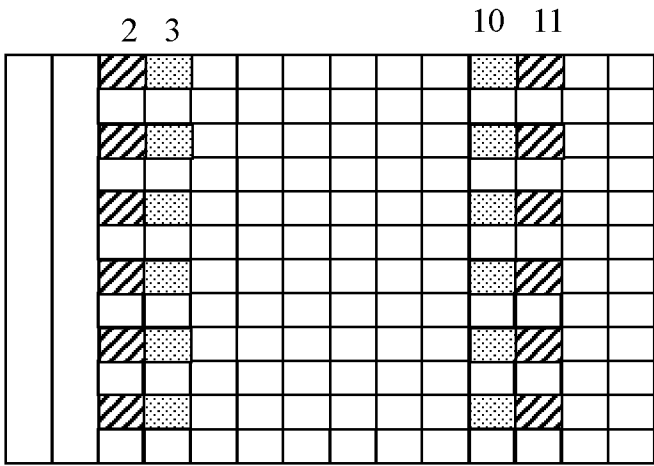


Fig. 2C

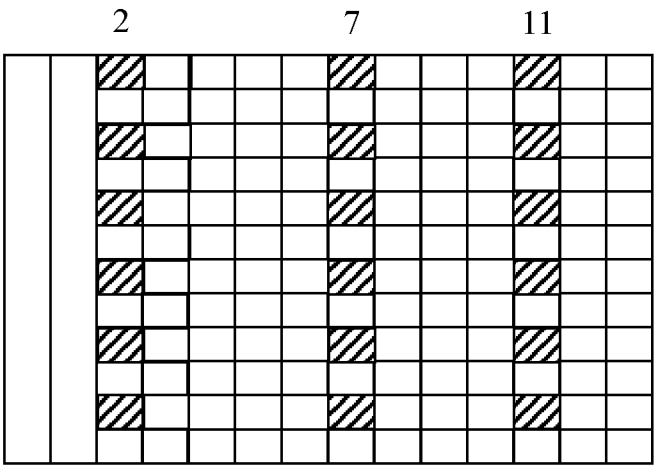


Fig. 2D

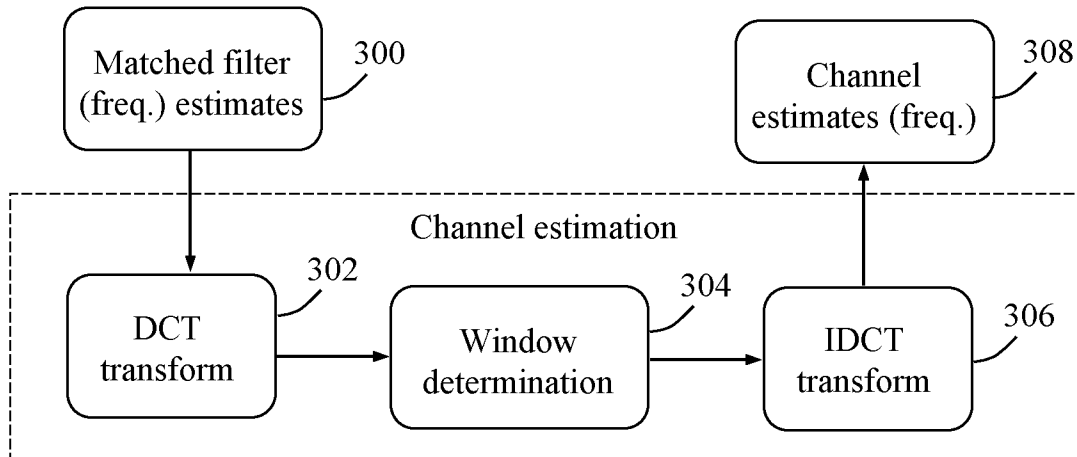


Fig. 3

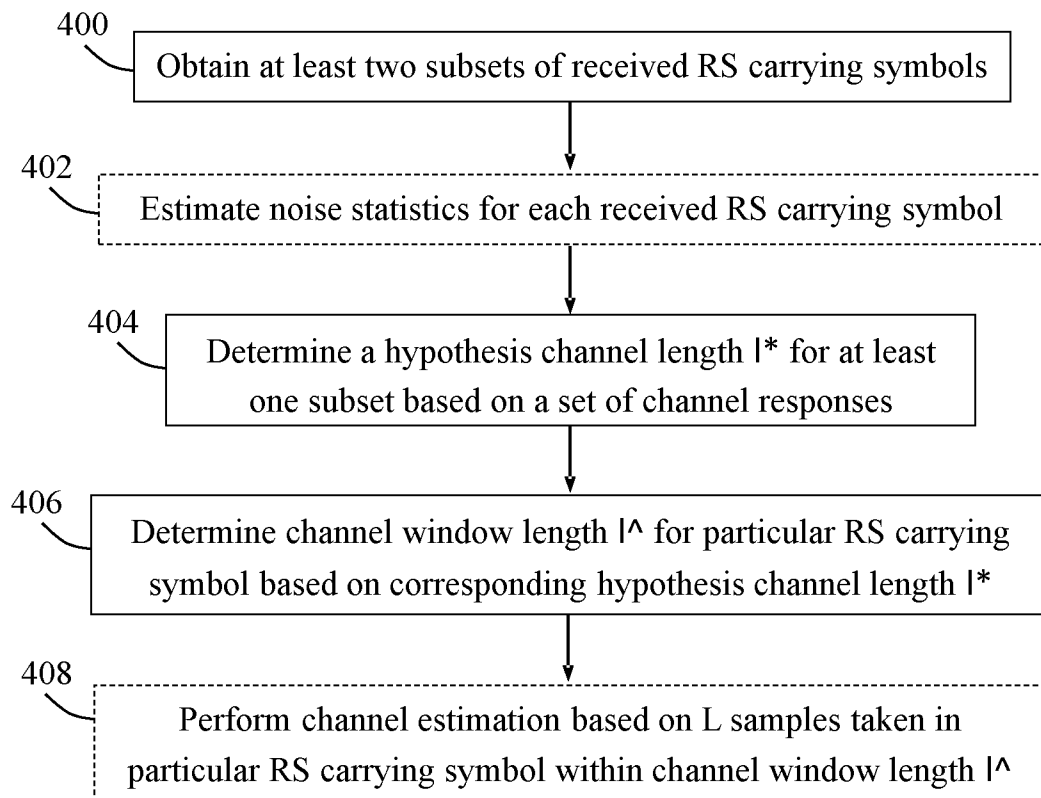


Fig. 4

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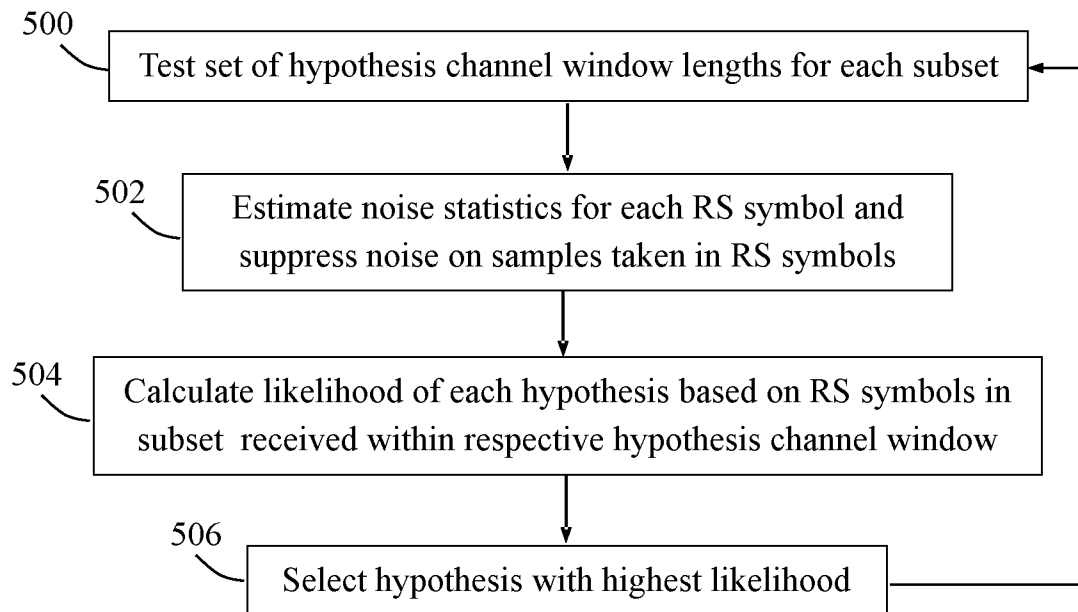


Fig. 5

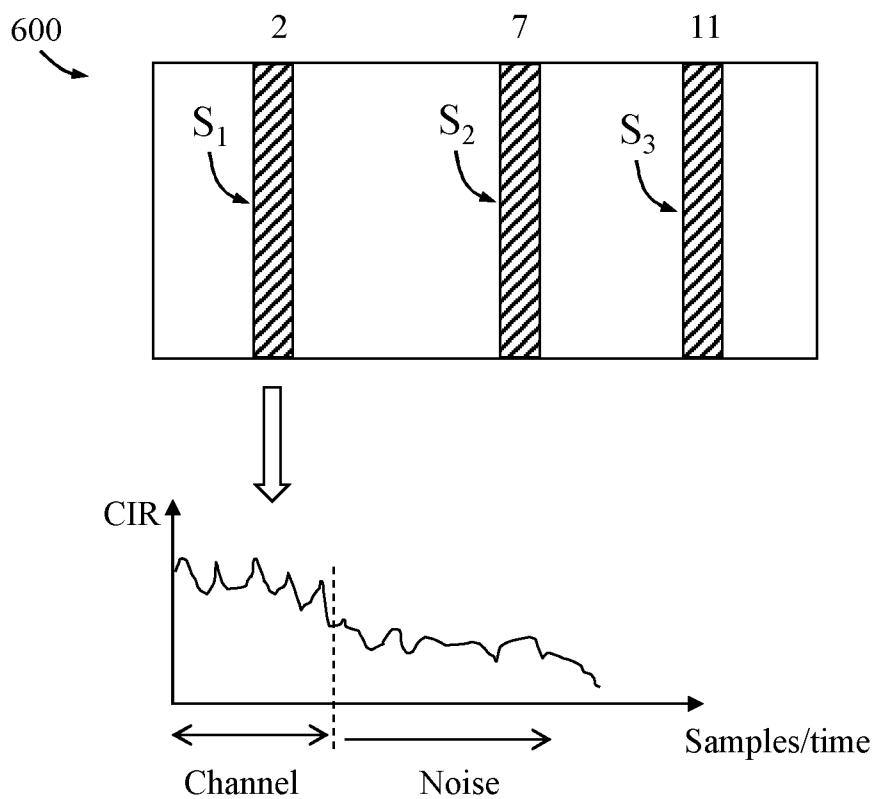


Fig. 6

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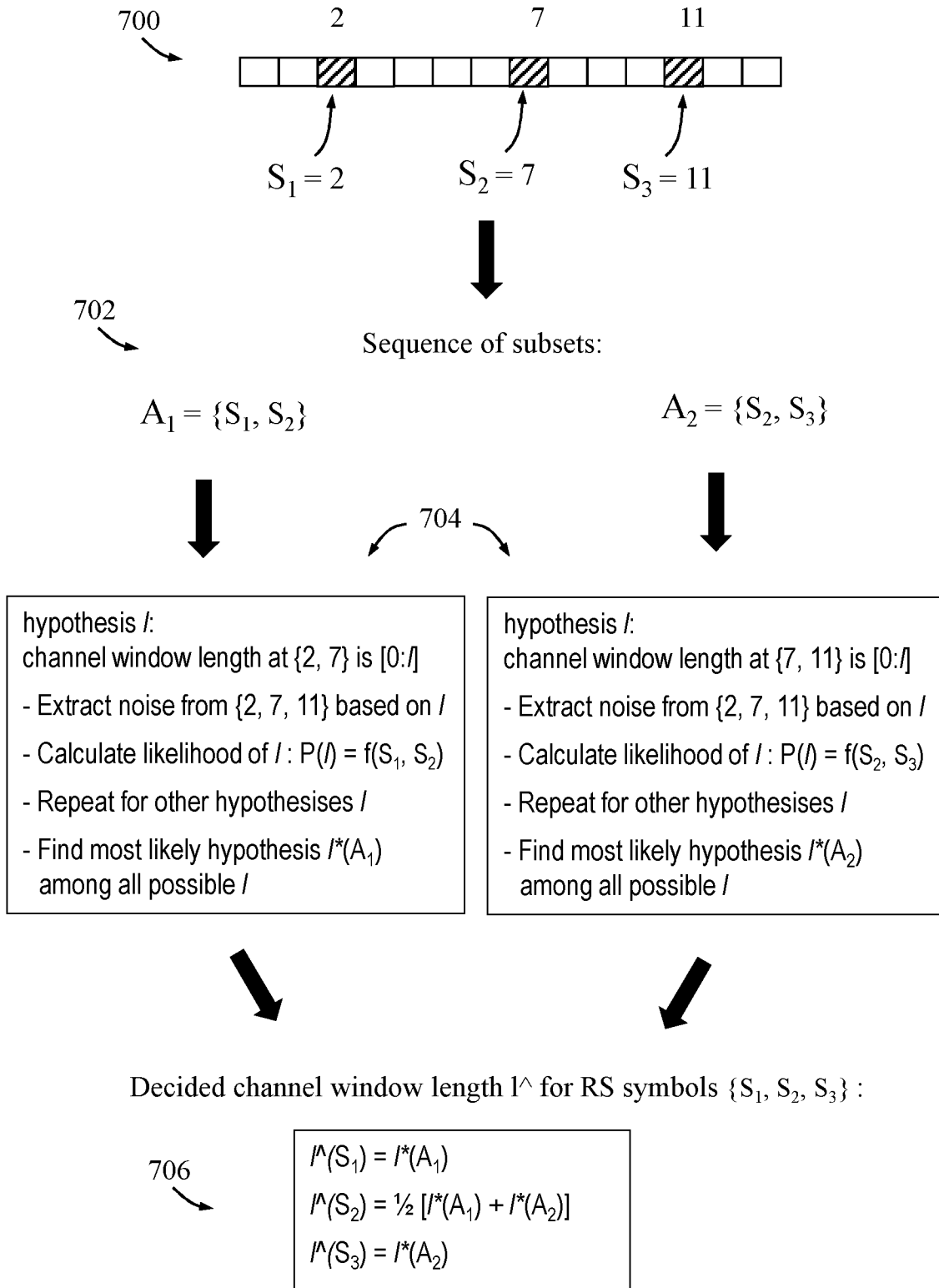


Fig. 7

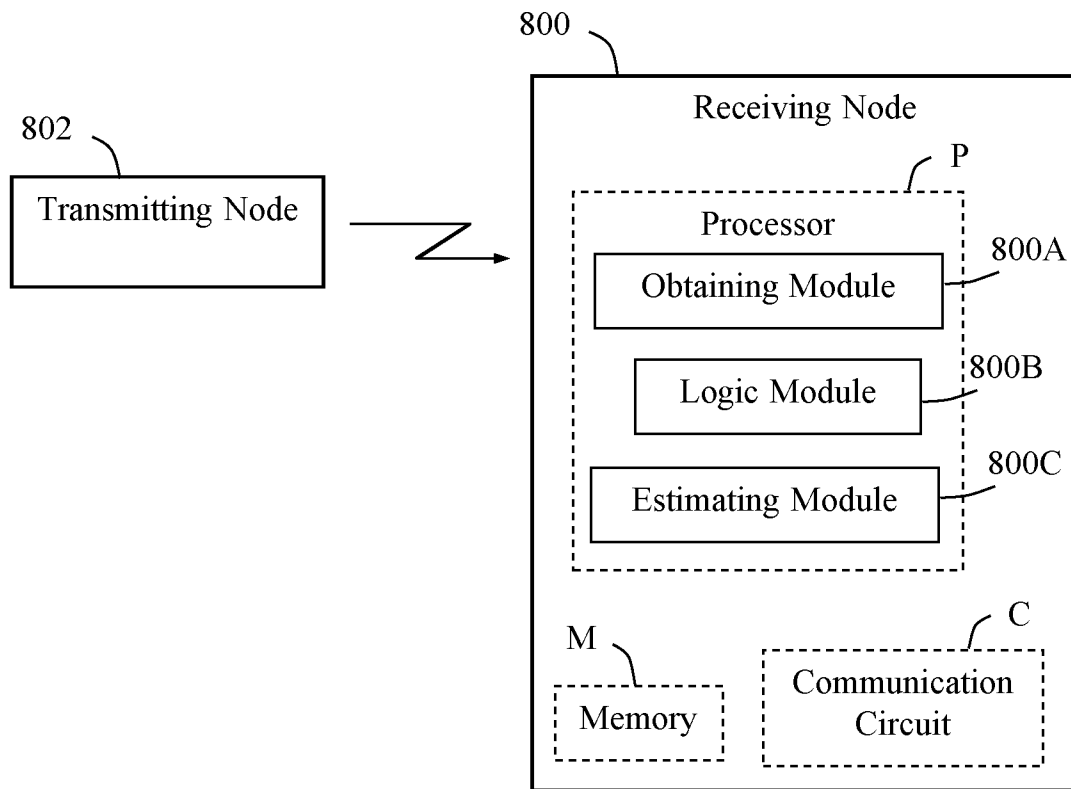


Fig. 8

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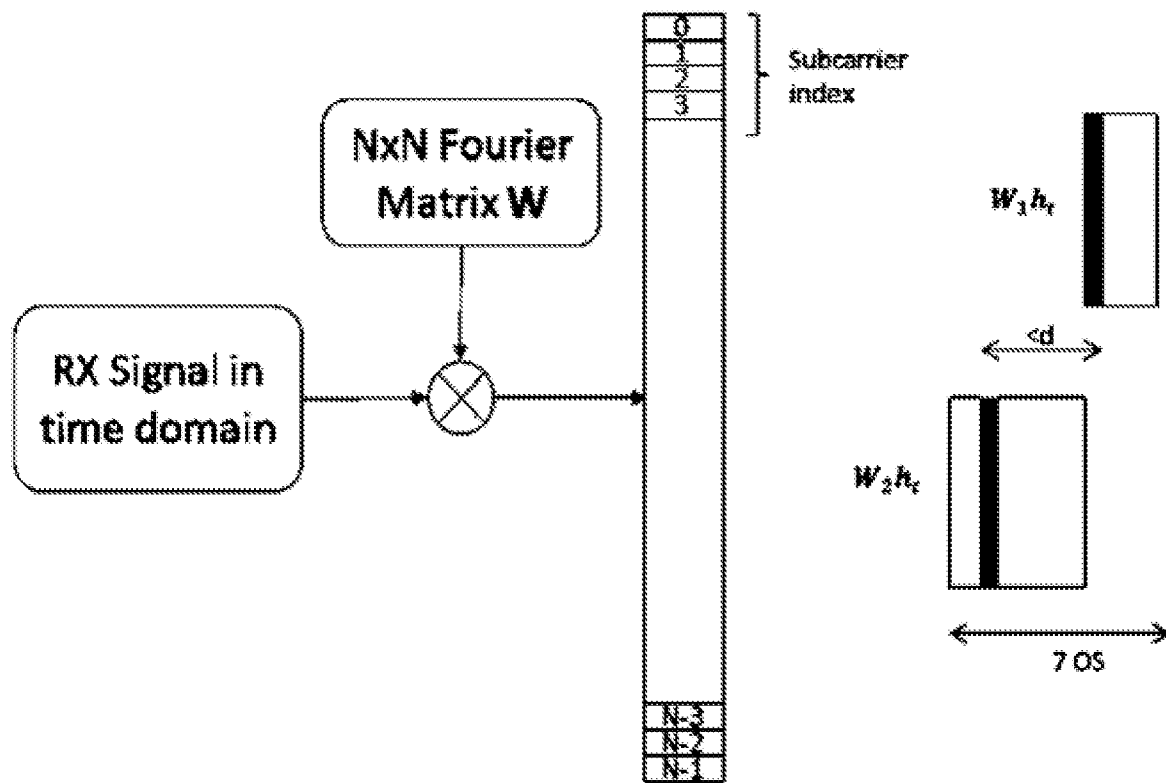


Fig. 9

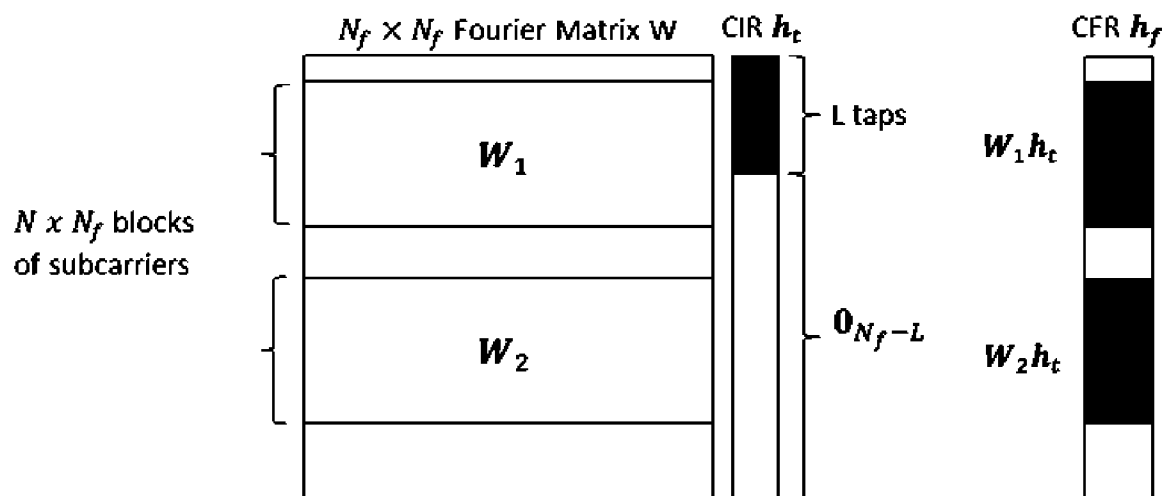


Fig. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2019/050006

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, PAJ, WPI data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 9219629 B1 (SUN NING ET AL), 22 December 2015 (2015-12-22); abstract; column 1, line 22 - column 1, line 30; column 4, line 13 - column 4, line 20; column 5, line 62 - column 5, line 65; column 6, line 61 - column 7, line 4; column 7, line 40 - column 8, line 28; figures 1-2,7,9-13; claims 1,12 --	1-28
A	CHOI J. "Multipath CDMA channel estimation by jointly utilising pilot and traffic channels" IEE Proceedings: Communications, Vol. 146 No. 5, 14-10-1999; ISSN: 1350-2425; whole document; pages 312-318 --	3-6, 8-9
A	US 20150156037 A1 (SAHLIN HENRIK ET AL), 4 June 2015 (2015-06-04); abstract; paragraphs [0019]-[0022] -- -----	1-28

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"D" document cited by the applicant in the international application	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
15-11-2019

Date of mailing of the international search report
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Continuation of: second sheet

International Patent Classification (IPC)

H04L 25/00 (2006.01)

H04L 27/26 (2006.01)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SE2019/050006

US	9219629 B1	22/12/2015	NONE		
US	20150156037 A1	04/06/2015	EP	2666269 B1	11/03/2015
			US	9413562 B2	09/08/2016
			US	20130287153 A1	31/10/2013
			WO	2012099511 A1	26/07/2012