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TIMING DETECTION METHOD, COMMUNICATION SYSTEM AND RECEIVING APPARATUS

Abstract

The transmission apparatus intermittently transmits a physical frame of a transmitted signal. The receiving apparatus includes a correlation calculation unit and a determination unit. The correlation calculation unit calculates a correlation between the received signal and each of the correlation sequences subjected to Doppler shift of a plurality of types of shift amounts. The determination unit determines that the physical frame has been received in a case where any one of the calculation results obtained by the correlation calculation unit exceeds the threshold.

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Background/Summary

TECHNICAL FIELD

[0001] The present invention relates to a timing detection method, a communication system, and a receiving apparatus.

BACKGROUND ART

[0002] In a communication system that performs transmission and reception in units of packets, it is necessary to accurately find a head position of a physical frame in order to perform synchronization processing. However, since there is impulse noise underwater, the timing of the impulse noise is often erroneously detected. In order to prevent erroneous timing detection in an environment with impulse noise, a relatively long correlation sequence may be embedded in a received signal, and frame timing detection may be performed by cross-correlation (e.g., refer to Non Patent Literature 1).

CITATION LIST

Non Patent Literature

[0003] Non Patent Literature 1: M. Stojanovic, J. A. Catipovic and J. G. Proakis, "Phase-coherent digital communications for underwater acoustic channels," in IEEE Journal of Oceanic Engineering, vol. 19, no. 1, pp. 100-111, January 1994, doi: 10.1109/48.289455

SUMMARY OF INVENTION

Technical Problem

[0004] The possibility of falsely detecting the impulse noise as the frame timing decreases as the correlation sequence becomes longer. On the other hand, the cross-correlation value between the Doppler-shifted received signal and the correlation sequence decreases as the correlation sequence becomes longer.

[0005] FIG. 6 is a diagram illustrating the detection performance of a conventional technology. FIG. 6 illustrates, as detection performance, a relationship between a moving speed and a cross-correlation value at the time of physical frame reception detection in the conventional technology. As the cross-correlation value, a normalized signal to noise ratio (SNR) is used. Reference sign L denotes a detectable level. When the cross-correlation value exceeds the detectable level L, the reception of the physical frame can be detected. Reference sign G11 denotes a cross-correlation value in a case where the sequence length is 25 ms, and reference sign G12 denotes a detectable range in a case where the sequence length is 25 ms. Reference sign G21 denotes a cross-correlation value in a case where the sequence length is 100 ms, and reference sign G22 denotes a detectable range in a case where the sequence length is 100 ms. As illustrated in FIG. 6, the cross-correlation value around the moving speed of 0 m/s becomes larger and the SNR is more improved as the sequence length becomes longer. This indicates that resistance to impulse noise is increased. On the other hand, the range of the moving speed in which the reception of the physical frame can be detected becomes narrower as the sequence length becomes longer.

[0006] In this way, it becomes difficult to detect the timing in a mobile environment if the correlation sequence is lengthened in order to improve the impulse noise resistance.

[0007] In view of the above circumstances, an object of the present invention is to provide a timing detection method, a communication system, and a receiving apparatus that improve the detection accuracy of a received signal in a mobile environment while preventing decrease in impulse noise resistance.

Solution to Problem

[0008] A timing detection method according to an aspect of the present invention includes: a

transmission step of intermittently transmitting a physical frame of a transmitted signal by a transmission apparatus; a correlation calculation step of calculating, by a receiving apparatus, a correlation between a received signal and each of correlation sequences subjected to Doppler shift of a plurality of types of shift amounts; and a determination step of determining, by the receiving apparatus, that the physical frame has been received in a case where any one of calculation results obtained in the correlation calculation step exceeds a threshold.

[0009] A timing detection method according to an aspect of the present invention includes: a correlation calculation step of calculating a correlation between a received signal and each of correlation sequences subjected to Doppler shift of a plurality of types of shift amounts; and a determination step of determining that a physical frame transmitted from a transmission apparatus that intermittently transmits a physical frame of a transmitted signal has been received in a case where any one of calculation results obtained in the correlation calculation step exceeds a threshold.

[0010] An aspect of the present invention is a communication system including a transmission apparatus and a receiving apparatus, in which the transmission apparatus intermittently transmits a signal frame, and the receiving apparatus includes: a correlation calculation unit that calculates a correlation between a received signal and each of correlation sequences subjected to Doppler shift of a plurality of types of shift amounts; and a determination unit that determines that the physical frame has been received in a case where any one of calculation results obtained by the correlation calculation unit exceeds a threshold.

[0011] A receiving apparatus according to an aspect of the present invention includes: a correlation calculation unit that calculates a correlation between a received signal and each of correlation sequences subjected to Doppler shift of a plurality of types of shift amounts; and a determination unit that determines that a physical frame transmitted from a transmission apparatus that intermittently transmits a physical frame of a transmitted signal has been received in a case where any one of calculation results obtained by the correlation calculation unit exceeds a threshold.

Advantageous Effects of Invention

[0012] According to the present invention, it is possible to improve the detection accuracy of a received signal in a mobile environment while preventing decrease in impulse noise resistance.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0013] FIG. 1 is a configuration diagram of a communication system according to an embodiment of the present invention.

[0014] FIG. 2 is a block diagram illustrating a configuration of a timing detection device according to an embodiment.

[0015] FIG. 3 is a flowchart illustrating reception timing detection processing by a timing detection device according to an embodiment.

[0016] FIG. 4 is a diagram illustrating a relationship between SNR and a Doppler shift amount.

[0017] FIG. 5 is a diagram illustrating detection performance of a timing detection device according to an embodiment.

[0018] FIG. 6 is a diagram illustrating detection performance of a conventional technology.

[0019] FIG. 7 is a block diagram illustrating a configuration of a conventional timing detection device.

[0020] FIG. 8 is a flowchart illustrating reception timing detection processing by a conventional timing detection device.

DESCRIPTION OF EMBODIMENTS

[0021] Hereinafter, an embodiment of the present invention will be described in detail with

reference to the drawings.

[0022] A communication system according to the present embodiment improves the detection accuracy of physical frame reception in a mobile environment while preventing decrease in impulse noise resistance without shortening the correlation sequence. As a result, the communication system according to the present embodiment accurately detects the reception timing of the physical frame of the signal even in an environment where impulse noise exists.

[0023] FIG. **1** is a diagram illustrating a configuration of a communication system **1** according to an embodiment of the present invention. The communication system **1** includes a transmitter **10** and a receiver **20**. The communication system **1** is, for example, an underwater communication system that performs underwater communication. In the case of performing underwater communication, the receiver **20** receives a signal transmitted underwater from the transmitter **10**.

[0024] The transmitter **10** intermittently transmits physical frames of transmitted signals from an antenna. The physical frame includes a payload and a correlation sequence. The correlation sequence is set at a predetermined position of the physical frame. In the present embodiment, a correlation sequence is set at the head of a physical frame. The correlation sequence is known.

[0025] The receiver **20** intermittently receives, by an antenna, the physical frames intermittently transmitted from the transmitter **10**. The receiver **20** includes a timing detection device **21**, a demodulation device **22**, and a shift amount calculation device **23**.

[0026] The timing detection device **21** calculates a correlation between the received signal received by the antenna and each of correlation sequences subjected to Doppler shift of a plurality of types of Doppler shift amounts, and detects the reception of the physical frame on the basis of the calculation results. The timing detection device **21** notifies the demodulation device **22** of the received signal and the detection position of the physical frame in the received signal.

[0027] The demodulation device **22** specifies the position of the payload in the received signal on the basis of the detection position of the physical frame detected by the timing detection device **21**. In a case where the correlation sequence is included at the head of the physical frame, the detection position in notification from the timing detection device **21** represents the head of the physical frame in the received signal. The demodulation device **22** demodulates a portion of the received signal corresponding to the payload of the physical frame to obtain the information transmitted by the transmitter **10**.

[0028] The shift amount calculation device **23** calculates a plurality of types of Doppler shift amounts to be applied to the correlation sequence used by the timing detection device **21**. Note that the shift amount calculation device **23** may be provided outside the receiver **20**. Moreover, the receiver **20** may not include the shift amount calculation device **23**. In this case, the timing detection device **21** uses a plurality of predetermined types of Doppler shift amounts set in advance.

[0029] Here, a conventional technology will be described. FIG. **7** is a diagram illustrating a configuration of a conventional timing detection device **91**. The timing detection device **91** includes a correlator **911** and a threshold determination unit **912**. The correlator **911** calculates a correlation value between the received signal and the correlation sequence. The threshold determination unit **912** detects the reception of the physical frame by comparing the correlation value with the threshold.

[0030] FIG. **8** is a flowchart illustrating reception timing detection processing by the timing detection device **91**. The correlator **911** inputs a received signal (step **S91**). The correlator **911** calculates cross-correlation between the received signal and the known correlation sequence (step **S92**). The threshold determination unit **912** determines whether the correlation value of the cross-correlation calculated in step **S92** is larger than a threshold or not (step **S93**).

[0031] When determining that the correlation value is smaller than or equal to the threshold (step **S93**: NO), the threshold determination unit **912** repeats the processing from step **S91** for a received signal at the next timing. When determining that the correlation value is larger than the threshold

(step S93: YES), the threshold determination unit **912** detects the reception of the physical frame. When the correlation sequence is at the head of the physical frame, the threshold determination unit **912** notifies the subsequent stage of the head position of the received signal inputted in step S91 as the detection position of the physical frame (step S94).

[0032] In the case of the timing detection device **91**, in principle, it is more difficult to detect the Doppler-shifted received signal as the correlation sequence becomes longer.

[0033] Next, the timing detection device **21** according to the present embodiment will be described. FIG. 2 is a diagram illustrating a configuration of the timing detection device **21**. The timing detection device **21** includes a branching unit **211**, N (N is an integer of 2 or more) correlators **212**, and a threshold determination unit **213**. The N correlators **212** are referred to as correlators **212-1** to **212-N**, respectively.

[0034] The branching unit **211** branches the received signal into N branches, and inputs the N -branched received signals to the correlators **212-1** to **212-N**, respectively. A correlator **212-n** (n is an integer of 1 or more and N or less) calculates a correlation value $C_{\text{sub}.n}$ between the received signal and a correlation sequence $A_{\text{sub}.n}$ obtained by applying Doppler shift of a frequency shift amount $f_{\text{sub}.n}$ [Hz] on the correlation sequence A . The frequency shift amounts $f_{\text{sub}.1}$ to $f_{\text{sub}.N}$ are different values. Any one of the frequency shift amounts $f_{\text{sub}.n}$ may be 0. For example, it is assumed that the frequency shift amount $f_{\text{sub}.1}$ of a correlator **212-1** is set to 0. In this case, the correlation sequence A is used as it is as the correlation sequence $A_{\text{sub}.1}$. In the present embodiment, a normalized SNR is used as the correlation value $C_{\text{sub}.n}$.

[0035] The threshold determination unit **213** detects the reception of a physical frame in a case where any one of the correlation values $C_{\text{sub}.1}$ to $C_{\text{sub}.N}$ calculated respectively by the correlators **212-1** to **212-N** exceeds the threshold. The threshold determination unit **213** outputs the received signal and the detection position of the physical frame to the demodulation device **22**.

[0036] FIG. 3 is a flowchart illustrating reception timing detection processing by the timing detection device **21**. The branching unit **211** inputs the received signal received by the antenna (step S11). The branching unit **211** branches the received signal into N branches, and inputs the N -branched received signals to the correlators **212-1** to **212-N**, respectively.

[0037] The correlator **212-n** calculates a correlation value $C_{\text{sub}.n}$ between a portion from the head of the received signal to the length of the correlation sequence A and a correlation sequence A_n obtained by applying $f_{\text{sub}.n}$ [Hz] Doppler shift on a known correlation sequence A (step S12-n). Here, the correlator **212-1** uses the correlation sequence A as it is as the correlation sequence $A_{\text{sub}.1}$. The correlator **212-n** outputs the calculated correlation value $C_{\text{sub}.n}$ to the threshold determination unit **213**.

[0038] The threshold determination unit **213** inputs the correlation values $C_{\text{sub}.1}$ to $C_{\text{sub}.N}$ calculated by the correlators **212-1** to **212-N** in steps S12-1 to S12-N, respectively. The threshold determination unit **213** determines whether any one of the correlation values $C_{\text{sub}.1}$ to $C_{\text{sub}.N}$ exceeds the threshold or not (step S13).

[0039] When determining that all of the correlation values $C_{\text{sub}.1}$ to $C_{\text{sub}.N}$ are equal to or less than the threshold (step S13: NO), the threshold determination unit **213** repeats the processing from step S11 for a received signal at the next timing. When determining that any one of the correlation values $C_{\text{sub}.1}$ to $C_{\text{sub}.N}$ exceeds the threshold (step S13: YES), the threshold determination unit **213** detects the reception of the physical frame. In a case where the correlation sequence is located the head of the physical frame, the threshold determination unit **213** notifies the demodulation device **22** of the head position of the received signal inputted in step S11 as the detection position of the physical frame (step S14).

[0040] As described above, the timing detection device **21** calculates the cross-correlation between the received signal and the Doppler-shifted correlation sequence in parallel in addition to the cross-correlation between the received signal and the known correlation sequence. As a result, it is possible to detect the Doppler-shifted received signal without sacrificing the detection accuracy.

[0041] Next, a method of calculating, by the shift amount calculation devices **23**, the frequency shift amounts set respectively for the correlators **212-1** to **212-N** of the timing detection device **21** will be described.

(First Calculation Method)

[0042] In a first calculation method, a Doppler frequency that cannot be detected can be eliminated. Since the Doppler frequency changes according to the moving speed, it can be said that a moving speed at which detection is impossible can be eliminated.

[0043] It is assumed that M denotes a sequence length of a correlation sequence, $f_{\text{sub.d}}$ denotes a Doppler frequency, $T_{\text{sub.s}}$ denotes a symbol rate, $\sigma_{\text{sub.s.sup.2}}$ denotes signal power of a received signal, and $\sigma_{\text{sub.n.sup.2}}$ denotes noise power of a received signal. The Doppler frequency is the amount of change between a frequency subjected to the Doppler effect and a frequency before being subjected to the Doppler effect. The signal power $S(f_{\text{sub.d}})$ at the time of received signal detection is expressed by the following Expression (1).

[Math . 1]

$$[00001] \text{ Signalpoweratthetimeofdetection } S(f_d) = \frac{2}{s} \frac{\sin^2(\frac{M f_d T_s}{2})}{\sin^2(\frac{f_d T_s}{2})} = \frac{2}{s} S'(f_d) \quad (1)$$

[0044] Expression (1) represents a value of a case where a correlation sequence having a Doppler shift amount of 0 is used. The noise power $N(f_{\text{sub.d}})$ at the time of physical frame reception detection is expressed by the following Expression (2).

[Math . 2]

$$[00002] \text{ Noisepoweratthetimeofdetection } N(f_d) = M \frac{2}{n} \quad (2)$$

[0045] The SNR at the time of physical frame reception detection is calculated by the following Expression (3) using Expressions (1) and (2).

[Math . 3]

$$[00003] \text{ SNRatthetimeofdetection: } \frac{S(f_d)}{N(f_d)} = \frac{\frac{2}{s} \times \frac{S'(f_d)}{M}}{\frac{2}{n}} = \text{SNR} \times \frac{S'(f_d)}{M} \quad (3)$$

[0046] It is assumed that the Doppler frequency $f_{\text{sub.d}}$ is expressed by the following Expression (4).

[Math . 4]

$$[00004] f_d = \frac{k}{MT_s}, (\text{Integer excluding } k \in 0) \quad (4)$$

[0047] In this case, the signal power is expressed as $S(f_{\text{sub.d}})=0$. That is, in a case where the Doppler frequency is expressed as $f_{\text{sub.d}}=k/(MT_{\text{sub.s}})$ [Hz], the SNR at the time of physical frame reception detection becomes 0, and thus signal detection cannot be performed. FIG. 4 is a diagram illustrating the relation between a correlation value and a Doppler shift amount at the time of physical frame detection. At the Doppler shift amounts f_a and f_b , the SNR, which is a correlation value, is 0, and therefore, signal detection is impossible. Therefore, the shift amount calculation device **23** shifts the Doppler frequency by $f_{\text{sub.d}}=1/(MT_{\text{sub.s}})$ [Hz] and sets the result for each correlator **212**. That is, the correlators **212-1** to **212-N** calculate correlation values with respect to the received signals by using correlation sequences Doppler-shifted by $f_{\text{sub.d}}=1/(MT_{\text{sub.s}})$. As a result, it is possible to eliminate the Doppler frequency at which $\text{SNR}=0$ is satisfied.

[0048] As described above, in the first calculation method, each of the plurality of types of Doppler shift amounts is set to any value obtained by multiplying the reciprocal $1/(MT_{\text{sub.s}})$ of the product $MT_{\text{sub.s}}$ of the sequence length M of the correlation sequence and the symbol rate $T_{\text{sub.s}}$ of the physical frame by an integer. Note that the number of sequences M of the correlation sequence is determined according to the range of the moving speed assumed for the communication apparatus including the transmitter **10** and the receiver **20**, that is, the Doppler shift amount assumed from the range of the moving speed. Moreover, the detection threshold is set on the basis of a receiver operating characteristic (ROC) according to a risk rate (significance level) required by the system

and detection power.

(Second Calculation Method)

[0049] The shift amount calculation device **23** determines the frequency shift amount by the following procedure. According to this method, the SNR of the lower detection limit can be secured.

[0050] (Procedure 1) The shift amount calculation device **23** generates a correlation sequence A of a Doppler frequency, which is 0, and sets the correlation sequence A as a correlation sequence A1. The shift amount calculation device **23** sets the correlation sequence A1 for the correlator **212-1**. This corresponds to regarding one Doppler shift amount (here, 0) among a plurality of types of Doppler shift amounts as a reference and setting a correlation sequence of a reference Doppler shift amount for the correlator **212-1**.

[0051] (Procedure 2) The shift amount calculation device **23** determines a detection threshold TH for the received signal of the Doppler frequency, which is 0, on the basis of the general ROC. The shift amount calculation device **23** obtains an SNR at the detection threshold TH of the received signal with the Doppler frequency, which is 0, and sets the SNR as C.sub.min.

[0052] (Procedure 3) When receiving the received signal in which the correlation sequence is set at the head of the physical frame, the shift amount calculation device **23** obtains the Doppler frequency $\pm f_{d1}$ that satisfies the condition expressed in the following Expression (5).

[Math. 5]

[00005]
$$\pm f_{d1}, \text{ such that } \frac{S(f_d)}{N(f_d)} = C_{\min}, \left(-\frac{1}{MT_s} < f_d < +\frac{1}{MT_s}\right) \quad (5)$$

[0053] That is, the ratio of the signal power S (f.sub.d) and the noise power N (f.sub.d) of the received signal calculated using the correlation sequence of the Doppler frequency $\pm f_{d1}$ matches the ratio C.sub.min of the signal power and the noise power of the received signal at the detection threshold calculated using the correlation sequence of the reference Doppler shift amount.

[0054] (Procedure 4) The shift amount calculation device **23** sets the correlation sequences A2 and A3 obtained by shifting the correlation sequence A1 by the Doppler frequency $\pm f_{d1}$ respectively for the correlators **212-2** and **212-3**. Furthermore, the shift amount calculation device **23** sets the correlation sequences A4 and A5 shifted by the Doppler frequency $\pm 2 \times f_{d1}$ respectively for the correlators **212-4** and **212-5**. Hereinafter, the shift amount calculation device **23** repeats up to the correlator **212-N**. As a result, the plurality of types of shift amounts have values shifted by the Doppler frequency f.sub.d1.

[0055] FIG. 5 is a diagram illustrating detection performance of the timing detection device **21** obtained by computer simulation. FIG. 5 also illustrates detection performance of the conventional timing detection device **91** for comparison. In this simulation, the correlation sequence length of the physical frame transmitted from the transmitter **10** is set to 100 ms, and the carrier frequency is set to 20 kHz. Moreover, the timing detection device **21** includes three correlators **212**, the correlator **212-1** uses a correlation sequence shifted by 0 Hz, the correlator **212-2** uses a correlation sequence shifted by 10 Hz, and the correlator **212-3** uses a correlation sequence shifted by -10 Hz. Moreover, the correlator **911** of the timing detection device **91** uses a correlation sequence shifted by 0 Hz. Moreover, the detectable SNR at the time of detection was set to -10 dB.

[0056] Reference sign L denotes a detectable level. In a case where the SNR is higher than the detectable level L, the reception of the physical frame can be detected. R11 denotes a detected SNR in the correlator **212** of the present embodiment, and R12 denotes a detectable range in the correlator **212** of the present embodiment. R21 denotes a detected SNR in a conventional correlator **911**, and R22 denotes a detectable range in the conventional correlator **911**. With reference to FIG. 5, according to the present embodiment, the range of the moving speed at which the physical frame can be detected is widened, and it can be seen that the frame detection accuracy in the mobile environment can be improved without sacrificing the sequence length.

[0057] Some of the functions of the receiver **20** in the above-described embodiment may be

implemented by a processor such as a central processing unit (CPU) or a graphics processing unit (GPU) reading and executing a program from a recording medium such as a memory. Moreover, some of the functions of the receiver **20** may be implemented by using hardware such as an application specific integrated circuit (ASIC), a programmable logic device (PLD), or a field programmable gate array (FPGA).

[0058] According to the above-described embodiment, the communication system includes a transmission apparatus and a receiving apparatus. For example, the transmission apparatus corresponds to the transmitter **10** in the embodiment, and the receiving apparatus corresponds to the receiver **20** in the embodiment. The transmission apparatus intermittently transmits a physical frame of a transmitted signal. The receiving apparatus includes a correlation calculation unit and a determination unit. The correlation calculation unit corresponds to, for example, the correlator **212** of the embodiment. The correlation calculation unit calculates a correlation between the received signal and each of the correlation sequences subjected to Doppler shift of a plurality of types of shift amounts. The received signal may be a signal transmitted underwater. The determination unit corresponds to, for example, the threshold determination unit **213** of the embodiment. The determination unit determines that the physical frame has been received in a case where any one of the calculation results obtained by the correlation calculation unit exceeds the threshold.

[0059] Each of the plurality of types of shift amounts is any value obtained by multiplying a reciprocal ($1/MT_{\text{sub.s}}$) of a product $MT_{\text{sub.s}}$ of the sequence length M of the correlation sequence and the symbol rate $T_{\text{sub.s}}$ of the physical frame by an integer.

[0060] Alternatively, the plurality of types of shift amounts are values shifted by a predetermined Doppler frequency $f_{\text{sub.d1}}$. In a case where one of the plurality of types of shift amounts is regarded as a reference, a ratio of the signal power $S(f_{\text{sub.d}})$ and the noise power $N(f_{\text{sub.d}})$ of the received signal calculated using the correlation sequence of the predetermined Doppler frequency $f_{\text{sub.d1}}$ matches an SNR (e.g., corresponding to $C_{\text{sub.min}}$ of the embodiment) that is a ratio of the signal power and the noise power of the received signal at the detection threshold calculated using the correlation sequence of the reference shift amount.

[0061] Although the embodiment of the present invention has been described in detail with reference to the drawings, specific configurations are not limited to the present embodiment and include design and the like within a scope not departing from the gist of the present invention.

REFERENCE SIGNS LIST

[0062] **1** Communication system [0063] **10** Transmitter [0064] **20** Receiver [0065] **21, 91** Timing detection device [0066] **22** Demodulation device [0067] **23** Shift amount calculation device [0068] **211** Branching unit [0069] **212-1** to **212-N, 911** Correlator [0070] **213, 912** Threshold determination unit [0071] **911** Correlator

Claims

1. A timing detection method comprising: intermittently transmitting, by a transmission apparatus, a physical frame of a transmitted signal; calculating, by a receiving apparatus, a correlation between a received signal and each of correlation sequences subjected to Doppler shift of a plurality of types of shift amounts; and determining, by the receiving apparatus, that the physical frame has been received in a case where any one of calculation results exceeds a threshold.
2. A timing detection method comprising: calculating a correlation between a received signal having been transmitted from a transmission apparatus that intermittently transmits a physical frame of a transmitted signal and each of correlation sequences subjected to Doppler shift of a plurality of types of shift amounts; and determining that the physical frame has been received in a case where any one of calculation results exceeds a threshold.
3. A communication system comprising a transmission apparatus and a receiving apparatus, wherein the transmission apparatus intermittently transmits a physical frame of transmitted signal,

and the receiving apparatus includes: a correlation calculation circuitry that calculates a correlation between a received signal and each of correlation sequences subjected to Doppler shift of a plurality of types of shift amounts; and a determination circuitry that determines that the physical frame has been received in a case where any one of calculation results obtained by the correlation calculation circuitry exceeds a threshold.

4. A receiving apparatus comprising: a correlation calculation circuitry that calculates a correlation between a received signal having been transmitted from a transmission apparatus that intermittently transmits a physical frame of a transmitted signal and each of correlation sequences subjected to Doppler shift of a plurality of types of shift amounts; and a determination circuitry that determines that the physical frame has been received in a case where any one of calculation results obtained by the correlation calculation circuitry exceeds a threshold.

5. The receiving apparatus according to claim 4, wherein each of the plurality of types of shift amounts is any value obtained by multiplying a reciprocal of a product of a sequence length of the correlation sequence and a symbol rate of the physical frame by an integer.

6. The receiving apparatus according to claim 4, wherein the plurality of types of shift amounts are values shifted by a predetermined Doppler frequency, and a ratio of signal power and noise power of a received signal calculated using a correlation sequence of the predetermined Doppler frequency matches a ratio of signal power and noise power of a received signal at a detection threshold calculated using a correlation sequence of a reference shift amount in a case where one of the plurality of types of shift amounts is regarded as the reference shift amount.

7. The receiving apparatus according to claim 4, wherein the received signal has been transmitted underwater.
