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COMMUNICATION DEVICE, COMMUNICATION METHOD, NON-TRANSITORY STORAGE MEDIUM STORING COMMUNICATION PROGRAM, AND COMMUNICATION SYSTEM

Abstract

A judgment unit determines that a low-priority time period during which transmission of frames by a node is set to be of low priority has ended. Upon receiving a notification of the end of the low-priority time period, an initial value change unit changes an initial value of a range that a waiting time can take to a value larger than a value of a normal time. A range determination unit determines the range using the changed initial value. A waiting time determination unit determines the waiting time from the determined range. A transmission unit waits for the determined waiting time and then starts transmitting the frames.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This application is a Continuation of PCT International Application No. PCT/J P2022/042854 filed on Nov. 18, 2022, all of which is hereby expressly incorporated by reference into the present application.

TECHNICAL FIELD
[0002] The present disclosure relates to a communication device, a communication method, a communication program, and a communication system.
BACKGROUND ART
[0003] There is a method for distributing transmission times by inserting a random waiting time before each communication device starts transmitting frames. By using this method, the probability of collision when a plurality of communication devices transmit frames can be reduced. However, if a possible range of the waiting time is fixed, the collisions cannot be sufficiently solved when the transmission opportunities are more likely to be concentrated than a normal time, and conversely, the waiting time cannot help but be longer than necessary when the transmission opportunities are less likely to be concentrated than the normal time. As a conventional technique for solving such a problem, for example, Patent Document 1 is known.
[0004] In the transmission method by a terminal (corresponding to the above-mentioned communication device) described in Patent Document 1, when entering a network, the terminal receives a message (hereinafter, referred to as a frame without particular distinction in the present disclosure) containing information about a window (corresponding to the above-mentioned possible range) of a backoff (corresponding to the above-mentioned waiting time) from a base station that has predicted the number of terminals entering the network, and determines a window for transmission using the information. Here, the information about the window is information for increasing an initial value of the window as compared with the case where the terminal has already participated in the network. In this way, when the terminals have the same nature as M2M devices (where a large number of terminals are configured to simultaneously participate in one network, and after a long sleep, enter the network to perform small-volume data transmission in a short time), the probability of collision can be reduced by enlarging the window in a situation where the transmission opportunities are more likely to be concentrated than the normal time, such as when the terminals enter the network.
[0005] In the example described in Patent Document 1, the times at which collisions are likely to occur (times at which terminals enter the network) arrive, triggered by transmission and reception of frames from the base station to the terminals (AAI-PAG-ADV in Patent Document 1). Therefore, as suggested in Patent Document 1, if the information about the window is contained in the frames, it is not necessary to transmit and receive additional frames, and consumption of communication resources can be suppressed.
PRIOR ART DOCUMENTS
Patent Documents
[0006] [Patent Document 1] Unexamined Japanese Patent Application Publication No. 2014-518476
SUMMARY OF THE INVENTION

Problems to be Solved by the Invention
[0007] On the other hand, there is a case where times at which collisions are likely to occur arrive without such transmission/reception of frames as a trigger. An example of such a case is a network in which a low-priority time period during which transmission of frames by a certain plurality of communication devices is of low priority is predetermined. During the low-priority time period, the plurality of communication devices accumulate transmission frames because it is difficult to obtain a transmission opportunity, and starts to transmit the accumulated transmission frames all at once immediately after the end of the low-priority time period, which makes it easy for collisions to occur. When the technology of Patent Document 1 is applied to such an example, it is necessary to transmit and receive additional frames containing information about the range that the waiting time can take, and thus consuming the communication resources.
[0008] The present disclosure is made to solve the above-described problem, and an object of the present disclosure is to prevent consumption of communication resources by eliminating the need to transmit and receive information about the range of waiting time between communication devices.
Means for Solving the Problems
[0009] A communication device according to the present disclosure is a communication device that participates in a network in which a low-priority time period during which transmission of transmission frames by the communication device itself is set to be of low priority is predetermined, the communication device includes: a judgment unit to determine that the low-priority time period has ended in the network; an initial value change unit to change an initial value of a width of a range that a waiting time before a start of the transmission can take to a value larger than a value of a normal time when receiving a notification of the end of the low-priority time period from the judgment unit; a range determination unit to determine the range using the changed initial value; a waiting time determination unit to determine the waiting time from the determined range; and a transmission unit to wait for the determined waiting time and then start the transmission of the transmission frames.
Effects of the Invention
[0010] The communication device according to the present disclosure participates in a network in which a low-priority time period during which transmission of transmission frames by the communication device itself is set to be of low priority is predetermined. In the network, the communication device determines that the low-priority time period ends, increases the initial value of the width of the range that the waiting time can take after the end of the low-priority time period to be larger than the normal time, and determines the range using the initial value. This eliminates the need for transmission and reception of information about the range of the waiting time between the communication devices, and prevents the communication resources from being consumed.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0011] FIG. **1** is a configuration diagram of a multi-hop network according to Embodiment 1.
[0012] FIG. **2** is a time chart showing a communication schedule of the multi-hop network according to Embodiment 1.
[0013] FIG. **3** is a diagram showing broadcasting in the multi-hop network according to Embodiment 1.
[0014] FIG. **4** is a time chart showing a waiting time according to Embodiment 1.
[0015] FIG. **5** is a hardware configuration diagram of a node according to Embodiment 1.
[0016] FIG. **6** is a functional block diagram of the node according to Embodiment 1.
[0017] FIG. **7** is a time chart showing an operation of a timer by a judgment unit according to

Embodiment 1.
[0018] FIG. **8** is a flowchart showing an operation of transmission by the node according to Embodiment 1.
[0019] FIG. **9** is a time chart showing an initial value to be changed by an initial value change unit according to Embodiment 1.
[0020] FIG. **10** is a time chart showing a relationship between a width of a range and its initial value according to Embodiment 1.
[0021] FIG. **11** is a time chart showing a relationship between the width of the range and its initial value according to Embodiment 2.
[0022] FIG. **12** is a time chart showing transmission times of broadcast frames according to Embodiment 3.
[0023] FIG. **13** is a functional block diagram of a node according to Embodiment 3.
[0024] FIG. **14** is a flowchart showing an operation of a reception unit and an estimation unit according to Embodiment 3.
[0025] FIG. **15** is a configuration diagram of a multi-hop network according to Embodiment 4.
[0026] FIG. **16** is a sequence diagram of an entry to the multi-hop network by a node according to Embodiment 4.
[0027] FIG. **17** is a functional block diagram of the node according to Embodiment 4.
[0028] FIG. **18** is a flowchart showing an operation of a parent candidate storage unit and a parent switching unit according to Embodiment 4.

EMBODIMENTS FOR CARRYING OUT THE INVENTION

Embodiment 1

[0029] The following describes Embodiment 1 in detail with reference to the drawings. Note that Embodiment 1 uses, as a description material, Wi-SUN FAN (Wi-SUN is a registered trademark; FAN stands for Field Area Network), which is a wireless communication standard of a multi-hop network for sensors. However, the network according to the present disclosure is not limited to the network conforming to the above-described standard, but may be any network in which a low-priority time period during which the transmission of a certain frame by a certain communication device is set to be of low priority is predetermined. The type of network is not limited as long as it meets the above requirement. For example, the network may be based on wireless communication of a cellular communication scheme, or it may be based on wired communication.
[0030] First, the configuration and operation of the multi-hop network will be described using the Wi-SUN FAN as an example.
[0031] FIG. **1** is a configuration diagram of the multi-hop network according to Embodiment 1. A multi-hop network **100** is configured of a plurality of nodes **101***a* to **101***g*. Hereinafter, when the nodes **101***a* to **101***g* are not distinguished, they are referred to simply as nodes **101**. In FIG. **1**, the nodes **101** linked by dotted arrows are wirelessly connected to each other.
[0032] The nodes **101** correspond to the communication devices according to the present disclosure. The multi-hop network **100** corresponds to the communication system according to the present disclosure.
[0033] The nodes **101** participating in the multi-hop network **100** are connected to other nodes **101** by wireless communication. Here, when attention is paid to a particular node **101**, among the nodes **101** directly connected to the particular node **101**, a node **101** on the upstream side is referred to as a parent node, and a node **101** on the downstream side is referred to as a child node. For example, the parent node of the node **101***b* is the node **101***a*. The child nodes of the node **101***b* are the node **101***d* and the node **101***e*. Therefore, for example, when the entire configuration of the multi-hop network **100** shown in FIG. **1** is described using the term child node, the child nodes of the node **101***a* are the node **101***b* and the node **101***c*, the child nodes of the node **101***b* are the node **101***d* and the node **101***e*, and the child nodes of the node **101***c* are the node **101***f* and the node **101***g*.
[0034] Each of the nodes **101** corresponds to one of Border Router **102**, Router **103**, and Leaf **104**.

[0035] The Border Router **102** is the most upstream node **101** in the multi-hop network **100**. In FIG. **1**, the node **101***a* corresponds to the Border Router **102**. The Border Router **102** is directly connected to an external network which is not shown (for example, the Internet or a cloud service) and relays communication between the multi-hop network **100** and the external network.
[0036] The Router **103** is not the most upstream node **101** (i.e., the Border Router **102**) but corresponds to the nodes **101** which have a child node. In FIG. **1**, the node **101***b* and the node **101***c* correspond to the Router **103**. Although FIG. **1** shows an example in which the Router **103** is configured of only one stage, the Router **103** may be configured of multiple stages. In other words, the parent (or a child) of the Router **103** may be a Router **103**.
[0037] The Leaf **104** corresponds to the nodes **101** which have no child node. In FIG. **1**, the nodes **101***d* to **101***g* correspond to the Leaf **104**.
[0038] A sensor device may be connected to the Router **103** or the Leaf **104**. The sensor device is, for example, a smart meter (electricity meter with communication function). In FIG. **1**, a smart meter **105***c* is connected to the node **101***c* which corresponds to the Router **103**, and a smart meter **105***g* is connected to the node **101***g* which corresponds to the Leaf **104**. The smart meter **105***c* transmits electricity quantity readings to the node **101***c*. The node **101***c* uploads the received electricity quantity readings to the external network via the multi-hop network **100**. The electricity quantity read by the smart meter **105***g* is also uploaded to the external network in a similar manner. Hereinafter, when the smart meter **105***c* and the smart meter **105***g* are not particularly distinguished, they are referred to as smart meters **105**.
[0039] FIG. **2** is a time chart showing a communication schedule of the multi-hop network **100** according to Embodiment 1. A Broadcast Dwell Interval (BDI) **111** is a time period for the Border Router **102** (i.e., the node **101***a*) to transmit broadcast frames or multicast frames. The BDI **111** arrives periodically at regular intervals, and the time width of each BDI **111** is identical. The start and end times of the BDI **111** are known in advance to all nodes **101** participating in the multi-hop network **100**. To be more specific, each of the nodes **101** receives information about the start and end times of the BDI **111** from the Border Router **102** when participating in the multi-hop network **100**. Each of the nodes **101** periodically receives the information about the start and end times of the BDI **111** even after participating in the multi-hop network **100**. Each node autonomously determines the start and end times of the BDI **111** based on the received information (details of the determination method will be described later with reference to FIG. **7**).
[0040] The broadcast frames and the multicast frames are frames addressed to the plurality of nodes **101** in the multi-hop network **100**. The broadcast frames are addressed to all of the nodes **101**, and the multicast frames are addressed to some of the nodes **101**.
[0041] FIG. **3** is a diagram showing broadcasting in the multi-hop network **100** according to Embodiment 1. The Border Router **102** generates broadcast frames **110** and transmits them to the node **101***b* and the node **101***c*, which are its own child nodes. Further, the node **101***b* relays the broadcast frames **110** to the node **101***d* and the node **101***e*, and the node **101***c* relays the broadcast frames **110** to the node **101***f* and the node **101***g*. That is, each of the nodes **101** which has received the broadcast frames **110** relays the broadcast frames **110** to its own child nodes **101**. The transmission and reception of the broadcast frames **110** in the multi-hop network **100** described above are performed within the time period of the BDI **111**, including the relaying by the lower-level nodes. This is the same for the multicast frames.
[0042] The description returns to FIG. **2**. The time period outside the time period of the BDI **111** is called a Unicast Dwell Interval (UDI) **124**. The transmission of unicast frames (frames addressed to one single node **101**) originating from any node **101** (including the Border Router **102**) is performed within the time period of the UDI **124**, that is, outside the BDI **111**. For example, the Router **103** or the Leaf **104** transmits the electricity quantity readings received from the smart meter **105** to the Border Router **102** by including it in the unicast frames. The Border Router **102** relays the frames to the external network.

[0043] Note that the BDI **111** corresponds to the low-priority time period during which transmission of transmission frames by each node itself is of low priority according to the present disclosure. To be more specific, for each of the plurality of nodes **101** (including the Border Router **102**) which wants to transmit a unicast frame, the BDI **111** corresponds to the low-priority time period during which transmission of the unicast frame by the node itself is of low priority. In other words, the low-priority time period during which the transmission of the transmission frames by the node itself is of low priority according to the present disclosure may be a time period during which the transmission of a certain frame is completely prohibited. In the Wi-SUN FAN, it is completely prohibited to transmit the unicast frames during the time period of the BDI **111**. Whether the transmission is completely prohibited or the transmission is of low priority (although not prohibited), the concentration of transmission opportunities is more or less caused after the end of such a time period.

[0044] Note that the low-priority time period during which the transmission of the transmission frames by the node itself is of low priority according to the present disclosure may not always periodically arrive at a constant interval and may not always be of the same time width. For example, the period and the time width may be updated to different values at a given time. In short, the start and end times of the low-priority time period should be known to the communication devices participating in the network before the low-priority time period actually arrives.

[0045] FIG. **4** is a time chart showing a waiting time according to Embodiment 1. The nodes **101** generate transmission frames **120** and store them in their own transmission queue. A necessary condition for a particular node **101** to be able to perform transmission (that is, the time at which transmission is allowed has arrived in FIG. **4**) is that the particular node **101** has stored a transmission frame **120** in the transmission queue and no other nodes **101** are performing transmission in the vicinity of the node **101**. In the present disclosure, the time at which transmission is allowed is also referred to as the transmission opportunity. When the transmission frame **120** is a unicast frame, it is also a necessary condition that the time is outside the BDI **111** in the multi-hop network **100**. If a particular node **101** which is within the time period of the BDI **111** stores a unicast frame in its own transmission queue, the particular node **101** is in a state in which it is allowed to perform transmission immediately after the BDI **111** ends. The nodes **101** each randomly select a waiting time **119** from a possible range **121** that the waiting time **119** can take (hereinafter, also simply referred to as the range **121**). As the width of the range **121** is larger, the transmission times of the transmission frames **120** are more distributed, and the probability of collision between the transmission frames **120** can be more reduced. On the other hand, the probability that the waiting time **119** becomes large increases, and the transmission is likely to be delayed. The nodes **101** each start transmission of the transmission frames **120** after the selected waiting time **119** has elapsed. However, if the start of transmission by another node **101** is detected before its own start of transmission of the transmission frames **120**, the nodes **101** each temporarily suspend the transmission of the transmission frames **120**. The suspended transmission is retried using the same means as in the case where a transmission frame **120** is not received successfully, which will be described later.

[0046] If a plurality of the nodes **101** existing in the vicinity start transmission at the same time, collisions between the transmission frames **120** occur, and both of the transmission frames **120** in collision are not received successfully. In this case, the plurality of nodes **101** reselect the waiting times **119**, and retry transmission of the transmission frames **120** after the times at which transmission is allowed have arrived. The probability of collision is further reduced by monotonically increasing the width of the range **121** each time retransmission is repeated. Note that there is an upper limit to the number of retries, and when the upper limit is reached, the node **101** being a transmission source discards the transmission frame **120**.

[0047] As described above, by inserting the random waiting times **119** and then transmitting the transmission frames **120**, the probability that the plurality of nodes **101** start transmission at the

same time is reduced, the probability of collision of transmission frames is reduced, and the communication resources can be used effectively.
[0048] Note that FIG. **4** illustrates an example in which the range **121** starts at the time when the node **101** is allowed to perform transmission. The examples described below in Embodiment 1 illustrate cases in which the range **121** starts at the time when the node **101** is allowed to perform transmission. However, in the communication devices according to the present disclosure, the range **121** may start with a short latency after the node **101** is allowed to perform transmission. In the communication devices according to the present disclosure, the selection of the waiting times **119** from the range **121** need not be completely random and may be biased to some extent.
[0049] The configuration and operation of the nodes **101** will be described focusing on the transmission of the unicast frames outside the BDI **111**. For convenience of description focusing on the above, in the following description of Embodiment 1, the term "transmission frames **120**" refers to unicast frames unless otherwise specified.
[0050] FIG. **5** is a hardware configuration diagram of the node **101** according to Embodiment 1. The node **101** includes a processor **106**, a memory **107**, a communication IF **108** (IF is an abbreviation of Interface), a timer **112**, and a bus **109**. The processor **106**, the memory **107**, the communication IF **108**, and the timer **112** transmit and receive signals to and from each other via the bus **109**. Note that the node **101** may include a connection IF (not shown) for connection with the smart meter **105**.
[0051] The processor **106** is, for example, a central processing unit (CPU), a digital signal processor (DSP), a graphical processing unit (GPU), or a field-programmable gated array (FPGA).
[0052] The memory **107** is, for example, a static random access memory (SRAM), a dynamic random access memory (DRAM), or a read-only memory (ROM). If the storage capacity of the memory **107** alone is insufficient, the node **101** may include an auxiliary storage device (not shown) as needed. The auxiliary storage device is, for example, a hard disk drive (HDD) or a solid state drive (SSD).
[0053] The communication IF **108** is a wireless communication module, and is an interface for communicating with other nodes **101**.
[0054] FIG. **6** is a functional block diagram of the node **101** according to Embodiment 1. The node **101** includes a judgment unit **113**, an initial value change unit **114**, a range determination unit **115**, a waiting time determination unit **116**, and a transmission unit **117**. The judgment unit **113**, the initial value change unit **114**, the range determination unit **115**, and the waiting time determination unit **116** are implemented as the processor **106**. Also, the transmission unit **117** is implemented as the communication IF **108**. Further, the judgment unit **113**, the initial value change unit **114**, the range determination unit **115**, the waiting time determination unit **116**, and the transmission unit **117** store data that needs to be held, in the memory **107** as appropriate. The transmission unit **117** includes a transmission queue (not shown).
[0055] The start and end of the BDI **111** is determined by the judgment unit **113**. To be more specific, the times until the arrival of the start and end times are counted using the timer **112** with the information about the start and end times of the BDI **111** received from the Border Router **102** as an input.
[0056] FIG. **7** is a timer chart showing an operation of the timer **112** by the judgment unit **113** according to Embodiment 1. When the node **101** participates in the network, it receives information about the start and end times of the BDI **111** from the Border Router **102**. The judgment unit **113** uses the information to calculate a remaining time until the start of the BDI **111**, sets the remaining time in the timer **112**, and causes the timer **112** to start counting down. The countdown of a timer value **118** proceeds at a constant rate. Immediately after receiving the notification of the expiration from the timer **112**, the judgment unit **113** determines that the start time of the BDI **111** has arrived, and also calculates the remaining time until the end of the BDI **111** and sets the remaining time in the timer **112**. Thereafter, the same procedure is used to determine that the start and end times of

the BDI **111** have arrived when the timer **112** expires. As described above, by determining the start and end of the BDI **111** using the timer **112**, the node **101** can autonomously determine the start and end of the BDI **111** without relying on external notification.

[0057] The operation of the timer **112** shown in FIG. **7** is an example. As another example, a timer **112** for determining the start of the BDI **111** and a timer **112** for determining the end of the BDI **111** may be provided separately. In this case, the values set in the timers **112** need to be changed as appropriate from the above description. The module used to measure time may not be a countdown timer, such as the timer **112** shown in Embodiment 1, but may be, for example, a clock for measuring and storing the current time. In this case, it is desirable for the communication devices on the network to synchronize their current times.

[0058] The description returns to FIG. **6**. The initial value change unit **114** changes the initial value of the width of the range **121**. The initial value is used directly as the width of the range **121** at the time of the first transmission of the transmission frames **120**. The change of the initial value by the initial value change unit **114** is performed only at the time of the first transmission of a transmission frame **120**, and is not performed at the time of the retry of the transmission of the transmission frame **120**. The operation of the initial value change unit **114** will be described in detail later using the flowchart in FIG. **8** and the time chart in FIG. **9**.

[0059] The range determination unit **115** determines the range **121** using the initial value changed by the initial value change unit **114**. The range determination unit **115** uses the initial value directly as the width of the range **121** at the time of the first transmission of a transmission frame **120**. If the transmission frame **120** is received successfully, the transmission of the transmission frame **120** is finished here, but if it is not received successfully, the transmission of the transmission frame **120** is retried. At the time of retry, the range determination unit **115** calculates the range **121** using the initial value and a predetermined function. A method that monotonically increases the width of the range **121** with each retry is used as the calculation method of the range **121**. For example, as a general method, there is a binary exponential backoff (BEB). The operation of the range determination unit **115** will be described in detail later using the flowchart in FIG. **8** and the time chart in FIG. **10**.

[0060] The waiting time determination unit **116** randomly determines the waiting time **119** from the range **121** determined by the range determination unit **115**. As described above, the selection of the waiting time **119** from the range **121** may not be completely random, and may be biased to some extent.

[0061] The transmission unit **117** waits for the waiting time **119** determined by the waiting time determination unit **116**, and then transmits the transmission frame **120**.

[0062] FIG. **8** is a flowchart showing the operation of transmission by the node **101** according to Embodiment 1. The node **101** checks whether a transmission frame **120** remains in the transmission queue (S**101**). If so, the process proceeds to step S**102**, otherwise it proceeds to step S**101**.

[0063] If a transmission frame **120** remains in the transmission queue, the transmission unit **117** takes out one transmission frame **120** from the transmission queue (S**102**), and the process proceeds to step S**103**.

[0064] The initial value change unit **114** changes, in accordance with the notification from the judgment unit **113**, the initial value of the width of the range **121** that the waiting time **119** can take (S**103**), and the process proceeds to step S**104**.

[0065] The range determination unit **115** determines the range **121** using the initial value changed in step S**103** (S**104**), and the process proceeds to step S**105**. Here, when the process proceeds directly from step S**103** to step S**104**, the width of the range **121** to be determined in step S**104** is the same value as the initial value changed in step S**103**. On the other hand, when the process proceeds from step S**108** to step S**104**, which will be described later, the range **121** to be determined in step S**104** is calculated using the initial value and the predetermined function. For example, if BEB is used as the calculation method of the range **121**, the range determination unit

115 calculates the range **121** such that the width of the range **121** increases with each transmission retry using a monotonically increasing exponential function.

[0066] The waiting time determination unit **116** randomly determines the waiting time **119** from the range **121** determined in step S**104** (S**105**), and the process proceeds to step S**106**.

[0067] The transmission unit **117** waits for the waiting time **119** from the time when the transmission is allowed (S**106**), and the process proceeds to step S**107**.

[0068] The transmission unit **117** transmits the transmission frame **120** (S**107**), and the process proceeds to step S**108**.

[0069] When the transmission unit **117** has confirmed that the transmission frame **120** has been successfully received at the destination node **101** (S**108**), the process proceeds to step S**101**, otherwise it proceeds to step S**109**. The node **101** determines that the transmission frame **120** has been successfully received, for example, when an acknowledge frame (ACK frame) is returned from the destination node **101** within a time limit.

[0070] The transmission unit **117** checks whether a retry limit of the transmission frame **120** has been reached (S**109**). If so, the process proceeds to step S**110**, otherwise it proceeds to step S**104**.

[0071] The transmission unit **117** discards the transmission frame **120** (S**110**) and the process proceeds to step S**101**.

[0072] FIG. **9** is a time chart showing the initial value changed by the initial value change unit **114** according to Embodiment 1. In FIG. **9**, the horizontal axis represents time, and the vertical axis represents the size of the initial value of the width of the range **121**. Here, a first time period **122** is defined as starting immediately after the end of the BDI **111** and ending at a middle time between the end time of the previous BDI **111** and the start time of the next BDI **111**. A second time period **123** is defined as an entire time period except the first time period **122**. The initial value change unit **114** changes the initial value of the width of the range **121** to N1, which is a value larger than a normal value N2, from immediately after the end of the BDI **111** (i.e., from immediately after the transition from the second time period **123** to the first time period **122**). The initial values N1 and N2 are constant values predetermined in the node **101** itself. Specifically, the values of N1 and N2 may be pre-stored in the memory **107** before the node **101** is shipped as a product. Alternatively, the values of N1 and N2 may be determined by a person installing the node **101** at a location where the node **101** will actually be used and written in the memory **107** at the time of the installation. The initial value change unit **114** returns the initial value to the normal value N2 at the time of transition from the first time period **122** to the second time period **123**. As described above, in the time period after the end of the BDI **111** in which the transmission opportunities of the transmission frames **120** are relatively likely to be concentrated, the initial value of the width of the range **121** that the waiting time **119** can take is set to the value N1 larger than the value N2 of the normal time so that the transmission of the transmission frames **120** is sufficiently distributed and the probability of collision of the transmission frames **120** can be reduced. Thus, the communication resources can be used effectively. On the other hand, in the time period during which the transmission of the transmission frames **120** is relatively less likely to be concentrated, the initial value of the width of the range **121** that the waiting time **119** can take is set to be normal so that it is possible to prevent the waiting time **119** from being unnecessarily expanded and to prevent the delay expansion of the transmission of the transmission frames **120**.

[0073] N1 and N2 used by the initial value change unit **114** need not always be constant values. The initial value change unit **114** may change the values of N1 and N2 in real time in accordance with the congestion status of the network as long as the size relationship of N1>N2 is satisfied. In order to grasp the congestion state of the network, the communication device measures, for example: the communication quality with the parent node and the child nodes (radio wave intensity or the like); the probability of success in the past transmission and reception; the number of other nodes **101** currently existing in the vicinity; the number of parent node and child nodes for the communication device itself; and the number of hops from the communication device itself to the

Border Router **102**. For example, if the number of surrounding nodes **101** is large, the transmission times of the transmission frames **120** by the plurality of nodes **101** are highly likely to overlap and cause collisions. Therefore, the initial value change unit **114** may change the value of N1 or N2 to a larger value. When the probability of success in the past transmission and reception is low, it is suspected that the failures have occurred due to the collisions between the transmission frames **120**, and therefore the initial value change unit **114** may change the value of N1 or N2 to a larger value. Specifically, the node **101** may change N1 or N2 to another predetermined value depending on whether the measurement result exceeds a predetermined threshold value. Alternatively, the node **101** may calculate the value of N1 or N2 by predetermining a function that takes the measurement result as an argument.

[0074] Also, the node **101** may change the end time of the first time period **122** in real time depending on how long the concentration of transmission opportunities of the transmission frames **120** continues. For example, the end time of the first time period **122** may be set to the time at which one-third of the time period from the end time of the previous BDI **111** to the start time of the next BDI **111** is to elapse. Further, the time widths of the first time periods **122** may not be the same, and the time widths of the second time periods **123** may not be the same. Further, instead of instantaneously returning the initial value from N1 to N2 at the moment of transition from the first time period **122** to the second time period **123**, the initial value may be monotonically decreased according to a predetermined function along with the elapse of time or the repetition of successful transmission during the first time period **122** and finally returned to the normal value N2. In the above example, the initial value change unit **114** needs to know information such as the arrival of the transition from the first time period **122** to the second time period **123**, the remaining time until the arrival, and the elapsed time after the arrival. In this regard, the judgment unit **113** may be designed to make a determination using the timer **112** and to notify the initial value change unit **114** of the determination.

[0075] FIG. **10** is a time chart showing the relationship between the width of the range **121** and the initial value according to Embodiment 1. In FIG. **10**, the determination of the range **121** by the range determination unit **115** is illustrated using an example of transmitting a total of five transmission frames **120**. In FIG. **10**, the horizontal axis represents time. The vertical axis represents the size of the width of the range **121** and the initial value thereof. As described above with reference to FIG. **9**, the initial value change unit **114** sets the initial value of the width of the range **121** to the value N1 larger than that of the normal time immediately after the transition from the second time period **123** to the first time period **122**, and returns the initial value to the value N2 of the normal time from immediately after the transition from the first time period **122** to the second time period **123**.

[0076] When the transmission of frame No. 1 is focused, the range determination unit **115** uses the value N1 as the width **121***a* of the range **121** in its first transmission. This is because, in the case of the first transmission, an initial value N1 changed by the initial value change unit **114** is directly used as the width of the range **121**. Thus, in the first transmission of the frame No. 1, the range determination unit **115** uses 0 as the lower limit of the range **121** (i.e., the range **121** is started at the same time as the node **101** is allowed to transmit the frames) and uses N1 as the upper limit of the range **121**.

[0077] Similarly, both the width **121***d* to be used for the first transmission of frame No. 2 and the width **121***f* to be used for the first transmission of frame No. 3 take the value N1 because they are determined in the first time period **122**. Both the width **121***g* to be used for the first transmission of frame No. 4 and the width **121***i* to be used for the first transmission of frame No. 5 take the value N2 because they are determined in the second time period **123**.

[0078] In the example of FIG. **10**, the range determination unit **115** increases the width of the range **121** with each transmission retry of the transmission frame **120**. For example, the node **101** attempted transmission of the frame No. 1 three times, including retries. When the width **121***a* used in the first transmission, the width **121***b* used in the second transmission, and the width **121***c* used in the third transmission are compared, the width **121***a*<the width **121***b*<the width **121***c* holds. Similarly, with respect to the transmission of the frame No. 2, when the width **121***d* used in the first transmission and the width **121***e* used in the second transmission are compared, the width **121***d*<the width **121***e* holds. Similarly, with respect to the transmission of the frame No. 4, when the width **121***g* used in the first transmission and the width **121***h* used in the second transmission are compared, the width **121***g*<the width **121***h* holds. Similarly, with respect to the transmission of the frame No. 5, when the width **121***i* used in the first transmission, the width **121***j* used in the second transmission, and the width **121***k* used in the third transmission are compared, the width **121***i*<the width **121***j*<the width **121***k* holds.

[0079] As described above, the communication device according to Embodiment 1 participates in a network in which a low-priority time period during which transmission of the transmission frames by the communication device itself is set to be of low priority is determined in advance, determines whether the low-priority time period has ended in the network, sets the initial value of the width of the range **121** that the waiting time **119** can take to the value N1 larger than the value N2 of the normal time for the time period immediately after the end of the low-priority time period, and determines the range **121** using the initial value. Thus, the communication device can change the initial value of the width of the range **121** that the waiting time **119** can take while autonomously determining the start and end of the low-priority time period without depending on a notification from the outside, and the consumption of the communication resources can be prevented by eliminating the need to transmit and receive information about the range that the waiting time can take between the communication devices.

[0080] In addition, in the time period after the end of the low-priority time period, in which the transmission opportunities of the transmission frames **120** are relatively likely to be concentrated, the initial value of the width of the range **121** that the waiting time **119** can take is set to the value N1 larger than the value N2 of the normal time so that the transmission of the transmission frames **120** is sufficiently distributed and the probability of collision of the transmission frames **120** can be reduced. Thus, the communication resources can be used effectively.

[0081] The judgment unit **113** determines an occurrence of transition from the first time period **122**, which is a time period from the end of the low-priority time period to the elapse of a predetermined time, to the second time period **123**, which is a time period except the first time period **122**. Upon receiving a notification of the occurrence of transition from the judgment unit **113**, the initial value change unit **114** returns the initial value of the width of the range **121** to the value N2 of the normal time. Thus, in the time period during which the transmission opportunities of the transmission frames **120** are relatively less likely to be concentrated, the initial value of the width of the range **121** that the waiting time **119** can take is set to be normal so that it is possible to prevent the waiting time from being unnecessarily expanded and to prevent the delay expansion of the transmission of the transmission frames **120**.

[0082] The judgment unit **113** determines the remaining time until the transition from the first time period **122**, which is a time period from the end of the low-priority time period to the elapse of a predetermined time, to the second time period **123**, which is a time period except the first time period **122**. By using the remaining time notified of by the judgment unit **113**, the initial value change unit **114** returns, before the transition occurs, the initial value of the width of the range **121** to the value N **2** of the normal time. This makes it possible to gradually return the initial value of the width of the range **121** to the normal value, and to change the initial value in accordance with the degree of concentration of the transmission opportunities of the transmission frames **120**.

[0083] Although Embodiment 1 has been described as an example of solving the problem of concentration of transmissions of the unicast frames after the end of the BDI **111**, the present disclosure can also be applied to solve the problem of concentration of transmissions (relaying) of the broadcast frames **110** or the multicast frames after the end of the UDI **124**. To be more specific, the Border Router **102** accumulates a large number of the broadcast frames **110** or the multicast frames in the transmission queue during the time period of the UDI **124**. After the end of the UDI **124**, the Border Router **102** transmits a large number of the broadcast frames **110** or the multicast frames and the plurality of nodes **101** relay these frames, which may cause congestion. Therefore, at the time of transition from the UDI **124** to the BDI **111**, the initial value of the width of the range **121** may be set to the value N1 larger than the value N2 of the normal time. In this way, after the end of the UDI **124**, the times of the transmissions (relaying) of the broadcast frames **110** or the multicast frames can be distributed, and the probability of collision of the transmission frames **120** can be reduced.

Embodiment 2

[0084] In Embodiment 2, an example in which the operations of the initial value change unit **114** and the range determination unit **115** are changed is shown.

[0085] FIG. **11** is a time chart showing a relationship between the width of the range and the initial value thereof according to Embodiment 2. In Embodiment 2, only the operation in the first time period **122** is changed from Embodiment 1, and the operation in the second time period **123** is not changed.

[0086] As a point similar to Embodiment 1, the initial value change unit **114** changes the initial value to N1 which is a value larger than the value N2 of the normal time immediately after the transition from the second time period to the first time period. Another point similar to Embodiment 1 is that, in the first attempt of transmission, the range determination unit **115** uses the initial value directly as the width of the range **121**. In the example of FIG. **11**, the transmission of the transmission frame No. 1 is successful in one attempt, and the width of the range **1211** used at that time is equal to the initial value N1.

[0087] Embodiment 2 differs from Embodiment 1 in that the initial value change unit **114** decrements the initial value at a fixed rate each time the transmission frame **120** is successfully transmitted in one attempt. In FIG. **11**, the transmission of the transmission frame No. 1 is successful in one attempt, so that the initial value in the transmission of the transmission frame No. 2 is decreased to N1b. Similarly, the transmission of the transmission frame No. 2 is successful in one attempt, so that the initial value in the transmission of the transmission frame No. 3 is decreased to N1c. That is, N1>N1b>N1c holds. Thus, the width **121***m* in the first attempt of the transmission of the transmission frame No. 2 is equal to the initial value N1b, and the width **121***n* in the first attempt of the transmission of the transmission frame No. 3 is equal to the initial value N1c.

[0088] As for the transmission of the transmission frame No. 3 (transmission frame **120**), an example is shown in which three attempts are made. That is, the transmission is unsuccessful twice. If the transmission is unsuccessful even once, the initial value change unit **114** changes the initial value to be used in the next transmission to N1. Therefore, the initial value in the transmission of the transmission frame No. 4 (transmission frame **120**) is N1, and N1 is used as the width of the range **121***q* in the first transmission of the same frame.

[0089] The range determination unit **115** always uses the value N1 as the width of the range **121** in the retry of the transmission. Therefore, the width **1210** in the second transmission of the transmission frame No. 3 (transmission frame **120**) and the width **121***p* in the third transmission of the same transmission frame are equal to the value N1.

[0090] As described above, in the communication device according to Embodiment 2, within the first time period **122**, the initial value change unit **114** sets the initial value in the next transmission of the transmission frame **120** to N1 when the retry of the transmission of the transmission frame **120** by the transmission unit **117** is required, and sets the initial value in the next transmission of the transmission frame **120** to be smaller than that in the previous transmission of the transmission frame **120** when the retry is not necessary. The range determination unit **115** directly uses the initial value changed by the initial value change unit **114** as the width of the range **121** at the first attempt of the transmission of the transmission frame **120**, and uses N1 as the width of the range **121** at the retry. Thus, the initial value can be made sufficiently large in the early stage of the first time period **122** and small in the late stage of the same time period in accordance with the nature that the transmission opportunities of the transmission frames **120** are likely to be concentrated in the early stage and unlikely to be concentrated in the late stage.

[0091] If the reception of the transmission frame **120** is unsuccessful and retransmission is required after the width of the range **121** is made smaller than N1, the width of the range **121** can be increased to N1 again, that is, the width of the range **121** can be increased again in accordance with the situation.

Embodiment 3

[0092] In addition to the improvement made to the width of the range **121** that the waiting time **119** can take as shown in Embodiment 1 and Embodiment 2, in Embodiment 3, a method of transmitting the unicast frames within the time period of the BDI **111** without interfering with the transmission and reception of the broadcast frames **110** and the multicast frames will be described. Although the time period of the BDI **111** is basically a time period during which the transmissions (relaying) of the broadcast frames **110** and the multicast frames are prioritized, in Embodiment 3, the unicast frames are transmitted using the opportunities of the intervals between the transmissions of the broadcast frames **110** and the multicast frames.

[0093] First, the periodicity of transmission of the broadcast frames **110** or the multicast frames, which is a premise of Embodiment 3, will be described.

[0094] FIG. **12** is a time chart showing the transmission times of the broadcast frames **110** according to Embodiment 3. In FIG. **12**, three of the broadcast frames **110** are shown being transmitted within one BDI **111**. Here, the period **127** in which each of the three broadcast frames **110** is transmitted is equal. As described above, some of the broadcast frames **110** transmitted by the Border Router **102** are transmitted at the constant period **127**. This point is the same for the multicast frames. In the multi-hop network **100** conforming to the Wi-SUN FAN, the period **127** is known to the nodes **101** in advance. Thus, each of the nodes **101** according to Embodiment 3 transmits the unicast frames using the opportunities, which is available in its vicinity, of the intervals between the periodic transmissions (relaying) of the broadcast frames **110** and the multicast frames.

[0095] FIG. **13** shows a functional block diagram of the node **101** according to Embodiment 3. The difference from Embodiment 1 is that a reception unit **125** and an estimation unit **126** are added. The reception unit **125** is implemented as the communication IF **108**. The estimation unit **126** is implemented as the processor **106**.

[0096] The reception unit **125** receives the broadcast frames **110** or the multicast frames transmitted from other nodes **101** within the time period of the BDI **111**. The reception unit **125** notifies the estimation unit of the time at which the reception occurred.

[0097] The estimation unit **126** estimates the time at which the broadcast frames **110** or the multicast frames are to be transmitted (relayed) next, using the time notified of by the reception unit **125** and the period **127** which is known in advance. The estimation unit **126** notifies the transmission unit **117** of the estimated time.

[0098] Since the broadcast frames **110** and the multicast frames include types having the periodicity and types not having the periodicity, the estimation unit **126** may estimate the period by focusing on the type having the periodicity. For this purpose, the estimation unit **126** needs to obtain information for distinguishing the above types. Such information can be provided for the estimation unit **126** by appropriately designing the reception unit **125** to analyze the reception frames for generating the information and to output the information to the estimation unit **126**.

[0099] When the period **127** is not known in advance, the estimation unit **126** may estimate the period **127** and estimate the time at which the broadcast frames **110** or the multicast frames are to be transmitted (relayed) next, using the estimated period **127**. For example, one method of estimating the period **127** is to receive the broadcast frames **110** or the multicast frames multiple times and estimate the period **127** from the intervals between the receptions. To increase the accuracy of the estimation, it is preferable to perform statistical processing, such as measuring the values of the intervals several times to obtain samples, using the average or median value of the samples as the estimated value of the period **127**, or removing samples with a deviation value of a specific level or higher as noise.

[0100] When it is estimated that the time at which the next broadcast frames **110** or the multicast frames are to be transmitted is approaching, the transmission unit **117** considers that it is not in a state in which transmission is possible (i.e. it does not perform transmission). Conversely, if the estimated time is distant from the current time, the transmission unit **117** determines, even within the time period during the BDI **111**, that the current time is a time at which the unicast frames can be transmitted. Note that the term “distant” means that there is sufficient time left to transmit one unicast frame.

[0101] FIG. **14** is a flowchart showing an operation of the reception unit and the estimation unit according to Embodiment 3.

[0102] Upon receiving a broadcast frame **110** or a multicast frame from the surrounding within the time period of the BDI **111** (S**201**), the reception unit **125** notifies the estimation unit **126** of the reception time of the broadcast frame **110** or the multicast frame of this time (step S**202**). Otherwise, the process returns to step S**201**.

[0103] The estimation unit **126** estimates the time at which the broadcast frames **110** or the multicast frames are to be transmitted (relayed) next, using the time notified of by the reception unit **125** and the period **127**, and notifies the transmission unit **117** of the estimated time (S**203**).

[0104] The transmission unit **117** may be configured not to transmit the unicast frames within the time period of the BDI **111** when the number of times the broadcast frames **110** or the multicast frames are transmitted within the time period of the BDI **111** is larger than a predetermined threshold value. The number of times can be statistically calculated by recording the past reception history.

[0105] As described above, the communication device according to Embodiment 3 includes the reception unit **125** that receives the reception frames within the low-priority time period and the estimation unit **126** that is notified of the time at which the reception frame is received from the reception unit **125** to estimate the next reception time of the reception frame using the reception time and the reception period **127** of the reception frames, and when the current time is distant from the estimated time within the low-priority time period, the transmission unit **117** considers that it is a time at which the transmission frame can be transmitted. Thus, even in the non-prioritized time period, low-priority frames can be transmitted without interfering with the communication of the frames to be prioritized, the low-priority frames can be prevented from accumulating in the transmission queue, and the transmission of the low-priority frames can be prevented from being concentrated immediately after the end of the non-prioritized time period.

Embodiment 4

[0106] Embodiment 4 shows a method of switching parent nodes when retransmissions occur frequently.

[0107] FIG. **15** is a configuration diagram of a multi-hop network **100** according to Embodiment 4. The difference from FIG. **1** and FIG. **3** is that a state before the node **101***e* participates in the multi-hop network **100** is shown here. That is, the node **101***e* is about to participate in the multi-hop network **100**, and it is not determined whether the node will become the Router **103** or the Leaf **104**. Hereinafter, in Embodiment 4, unless otherwise specified, the example in which the node **101***e* is about to participate in the multi-hop network **100** will be used for description.

[0108] The node **101***e* checks the presence of the surrounding nodes **101** (hereinafter also referred to as neighboring nodes), and constructs a route to the Border Router **102** based on information from the neighboring nodes. To be more specific, by using metrics (hereinafter, also referred to as rank values) announced by the neighboring nodes and the rank values from itself to the neighboring nodes, the node **101***e* calculates the rank value from itself to the Border Router **102**. The rank value is a numerical value indicating a virtual distance in the network, and the larger the value is, the farther the virtual distance is (for example, the latency is large). The number of hops may be used as the rank value. Alternatively, the rank value may be calculated based on the communication bandwidth. The node **101***e* prioritizes the neighboring nodes whose calculated rank values are equal to or lower than a threshold value in accordance with the calculated rank values, and records the prioritized neighboring nodes in a parent candidate list stored therein. The node **101***e* participates in the multi-hop network **100** by selecting the parent candidate having the highest priority as the parent node from among the parent candidate list stored therein. The details of the above-described operation will be described with reference to FIG. **16**.

[0109] FIG. **16** is a sequence diagram illustrating the participation of the node **101***e* in the multi-hop network **100** according to Embodiment 4.

[0110] The node **101***e* transmits a request for participation in the multi-hop network **100** to the neighboring node **129** (step S**301**). Here, there may be a plurality of the neighboring nodes **129**.

[0111] The neighboring node **129** that has received the request for participation from the node **101***e* returns information necessary for the node **101***e* to participate in the multi-hop network **100** (step S**302**).

[0112] The node **101***e* transmits a request for a rank value to the neighboring node **129** that returned the necessary information (step S**303**).

[0113] Upon receiving the request for the rank value from the node **101***e*, the neighboring node **129** returns, to the node **101***e*, the rank value from itself (the neighboring node **129**) to the Border Router **101** (step S**304**).

[0114] The node **101***e* records, in accordance with a condition, some of the neighboring nodes **129** that have returned the rank values in the parent candidate list and determines the parent node (step S**305**). The specific operation of step S**305** will be described below. The node **101***e* calculates the rank values from itself (the node **101***e*) to the neighboring nodes **129**. This calculation may be performed using the statistics information of the frames transmitted and received in the past. The node **101***e* calculates the rank values from itself (the node **101***e*) to the Border Router **102** using the rank values from itself (the node **101***e*) to the neighboring nodes **129** and the rank values from the neighboring nodes **129** to the Border Router **102**. The node **101***e* records the neighboring nodes **129** having the rank values from itself (the node **101***e*) to the Border Router **102** equal to or lower than a threshold value in the parent candidate list stored in itself (the node **101***e*) together with the priorities determined according to the rank values. The node **101***e* determines the neighboring node **129** with the highest priority as the parent node. That is, the node **101***e* transmits the frames to the destination via the parent node determined by itself when transmitting the frames in the uplink thereafter.

[0115] The node **101***e* notifies the neighboring node **129** determined as the parent node in step S**305** that it has been determined as the parent node (step S**306**).

[0116] The neighboring node **129** that has received the notification relays the notification to the Border Router **102** (step S**307**). When relaying the notification to the Border Router **102**, the neighboring node **129** that has received the notification may add information indicating which node is the parent node of itself (the neighboring node **129**) to the notification.

[0117] Next, a method will be described in which, after the node **101***e* participates in the multi-hop network **100**, the node **101***e* switches its own parent node to another candidate when retransmissions are occurring (or have come to occur) frequently.

[0118] FIG. **17** is a functional block diagram of the node **101** according to Embodiment 4. The difference from Embodiment 1 is that Embodiment 4 includes a parent candidate storage unit **130** and a parent switching unit **131**. The parent candidate storage unit **130** and the parent switching unit **131** are implemented as the processor **106**. From among the neighboring nodes **129**, the parent candidate storage unit **130** stores, as the parent candidate list in the memory **107**, those that result in the rank values from itself (the node **101**) to the Border Router **102** equal to or lower than a threshold value. After the end of the BDI **111**, the parent switching unit **131** selects the parent node from the parent candidate list stored in the parent candidate storage unit and switches the parent to the selected node.

[0119] FIG. **18** is a flowchart showing an operation of the parent candidate storage unit **130** and the parent switching unit **131** according to Embodiment 4. Here, it is assumed that the node **101** participates in the multi-hop network **100** before the start of the flowchart in FIG. **18**. That is, the flowchart in FIG. **18** shows an operation of switching the parent to another neighboring node **129**. After the end of the BDI **111**, the flowchart in FIG. **18** is executed before the unicast frames in the transmission queue are transmitted, for example. Alternatively, only step S**407** in the flowchart of FIG. **18** is executed at the time mentioned above, and the other steps in the flowchart of FIG. **18** may be executed before the time mentioned above.

[0120] The parent switching unit **131** accumulates information about the success or failure of transmission notified from the transmission unit **117**, and calculates the past retransmission probability in accordance with the information (step S**401**). The transmission unit **117** determines whether the transmission is successful or not based on the determination result of step S**108** shown in FIG. **8**. Alternatively, the transmission unit **117** may calculate the retransmission probability and notify the parent switching unit **131** of the calculated retransmission probability.

[0121] The parent switching unit **131** determines whether the calculated retransmission probability is equal to or larger than a threshold value (step S**402**), and if it is equal to or larger than the threshold, the process proceeds to step S**403**, and if not, the flowchart of FIG. **18** is terminated.

[0122] The parent switching unit **131** refers to the parent candidate list stored in the parent candidate storage unit **130** to determine whether there is another candidate for the parent (step S**403**), and if there is, the process proceeds to step S**404**, and if not, the flowchart of FIG. **18** is terminated.

[0123] The parent switching unit **131** determines, using a random number, whether to perform parent node switching (step S**404**), and if it is to be performed, the process proceeds to step S**405**, and if not, the flowchart of FIG. **18** is terminated. Here, the random number is a random number based on a uniform probability distribution for determining whether or not to switch the parent node, and whether or not to switch the parent node is determined probabilistically.

[0124] The parent switching unit **131** selects the neighboring node **129** with the next highest priority of the current parent node as a candidate in the parent candidate list (step S**405**), and the process proceeds to step S**406**.

[0125] The parent switching unit **131** determines whether the difference in the rank value between the current parent and the candidate selected in step S**405** is lower than a threshold value (step S**406**), and if it is lower than the threshold value, the process proceeds to S**407**, and if not, the flowchart of FIG. **18** is terminated.

[0126] The parent switching unit **131** switches the selected candidate and the current parent (step S**407**), and the flowchart of FIG. **18** is terminated.

[0127] As described above, the communication device according to Embodiment 4 includes the parent candidate storage unit that stores the communication devices having the rank values equal to or lower than a threshold value as the parent candidates, and the parent switching unit that switches the parent of the communication device itself to another communication device after the end of the low-priority time period when the retransmission probability is high, and the parent switching unit selects the parent to switch to from the stored candidates. Thus, the parent to which the transmission frames **120** is transmitted can be switched after the end of the low-priority time period when the retransmission probability is high, and the retransmission probability can be reduced.

[0128] Further, by limiting the parent switching to only the transmission of the transmission frames **120** after the end of the low-priority time period, it is possible to use a route with the best

communication environment for the transmission frames **120** to be transmitted at other times.
[0129] The condition for switching the parent may be changed according to the surrounding situation. The degree of congestion and communication quality of the surroundings can be used in this case. For example, when the number of frames observed within a given time period is equal to or less than a predetermined threshold value and the rank value is good (small), the determination of the random number in step S**404** may be adjusted or the threshold value of the difference in the rank value between the current parent and the candidate in step S**406** may be decreased in such a manner as to decrease the probability of switching the parent. The communication device can calculate the degree of congestion and the communication quality of the surroundings using, for example, the statistic information obtained from the communication state, the rank values, and the number of neighboring communication devices.
DESCRIPTION OF SYMBOLS
[0130] **100** . . . multi-hop network, [0131] **101**_a_ to **101**_g_ . . . node, [0132] **102** . . . Border Router, [0133] **103** . . . Router, [0134] **104** . . . Leaf, [0135] **105**_c_ . . . smart meter, [0136] **105**_g_ . . . smart meter, [0137] **106** . . . processor, [0138] **107** . . . memory, [0139] **108** . . . communication IF, [0140] **109** . . . bus, [0141] **112** . . . timer, [0142] **113** . . . judgment unit, [0143] **114** . . . initial value change unit, [0144] **115** . . . range determination unit, [0145] **116** . . . waiting time determination unit, [0146] **117** . . . transmission unit, [0147] **118** . . . timer value, [0148] **110** . . . broadcast frame, [0149] **111** . . . BDI, [0150] **119** . . . waiting time, [0151] **120** . . . transmission frame, [0152] **121** . . . range, [0153] **121**_a_ to **121**_q_ . . . width of range, [0154] **122** . . . first time period, [0155] **123** . . . second time period, [0156] **124** . . . UDI, [0157] **125** . . . reception unit, [0158] **126** . . . estimation unit, [0159] **127** . . . period, [0160] **129** . . . neighboring node, [0161] **130** . . . parent candidate storage unit, [0162] **131** . . . parent switching unit

Claims

1. A communication device that participates in a network in which a time period during which transmission of transmission frames by the communication device itself is set to be of low priority is predetermined, the communication device comprising: a processor to execute a program; and a memory to store the program which, when executed by the processor, performs processes of, determining that the low-priority time period has ended in the network; changing an initial value of a width of a range that a waiting time before a start of the transmission can take to a value larger than a value of a normal time when receiving a notification of the end of the low-priority time period; determining the range using the changed initial value; determining the waiting time from the determined range; and waiting for the determined waiting time and then start the transmission of the transmission frames.
2. The communication device according to claim 1, wherein the waiting time is determined at random from the range.
3. The communication device according to claim 2, wherein the initial value is used directly as the width of the range in a first attempt of transmission of the transmission frames.
4. The communication device according to claim 3, wherein an occurrence of a transition from a first time period being a period of time from the end of the low-priority time period to an elapse of a predetermined time, to a second time period being a period of time except the first time period is determined, and the initial value of the width of the range is returned to the value of the normal time when the notification of the occurrence of the transition is received.
5. The communication device according to claim 3, wherein a remaining time until a transition from a first time period being a period of time from the end of the low-priority time period to an elapse of a predetermined time, to a second time period being a period of time except the first time period is determined, and the initial value of the width of the range is returned to the value of the normal time by using the notified remaining time before the transition.

6. The communication device according to claim 4, wherein, within the first time period, the initial value in the next transmission of the transmission frames is set to the larger value when a retry of the transmission of the transmission frames is required, and the initial value in the next transmission of the transmission frames is set to be smaller than that in the previous transmission of the transmission frames when the retry is not required, and the larger value is used as the width of the range when the transmission of the transmission frames is retried.
7. The communication device according to claim 1, wherein the program further performs processes of, receiving a reception frame within the low-priority time period; and being notified of a time at which the reception frame is received and estimating a next reception time of a reception frame using the time at which the reception frame is received and a reception period of the reception frame, wherein, when a current time is distant from the estimated time within the low-priority time period, it is considered that it is a time at which a transmission frame can be transmitted.
8. The communication device according to claim 1, wherein the program further performs processes of, storing a communication device whose rank value is equal to or lower than a threshold value as a candidate for a parent; switching its parent to another communication device after the end of the low-priority time period when a retransmission probability is high, wherein a parent to switch to is selected from among the stored candidates.
9. A communication method to be used by a communication device that participates in a network in which a time period during which transmission of transmission frames by the communication device itself is set to be of low priority is predetermined, the communication method comprising: determining that the low-priority time period has ended in the network; changing an initial value of a width of a range that a waiting time before a start of the transmission can take to a value larger than a value of a normal time when determining the end of the low-priority time period; determining the range using the changed initial value; determining the waiting time from the determined range; and waiting for the determined waiting time and then starting the transmission of the transmission frames.
10. A non-transitory storage medium storing a communication program causing a computer that participates in a network in which a time period during which transmission of transmission frames by the computer itself is set to be of low priority is predetermined to perform processes of: determining that the low-priority time period has ended in the network; changing an initial value of a width of a range that a waiting time before a start of the transmission can take to a value larger than a value of a normal time when receiving a notification of the end of the low-priority time period from the determining process; determining the range using the changed initial value; determining the waiting time from the determined range; and waiting for the determined waiting time and then starting the transmission of the transmission frames.
11. A communication system comprising a plurality of communication devices each of which participates in a network in which a time period during which transmission of transmission frames by the communication device itself is set to be of low priority is predetermined, the communication device comprising: a processor to execute a program; and a memory to store the program which, when executed by the processor, performs processes of, determining that the low-priority time period has ended in the network; changing an initial value of a width of a range that a waiting time before a start of the transmission can take to a value larger than a value of a normal time when receiving a notification of the end of the low-priority time period; determining the range using the changed initial value; determining the waiting time from the determined range; and waiting for the determined waiting time and then start the transmission of the transmission frames.