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(54) Title: WIRELESS COMMUNICATIONS DEVICE WAKEUP METHOD AND SYSTEM

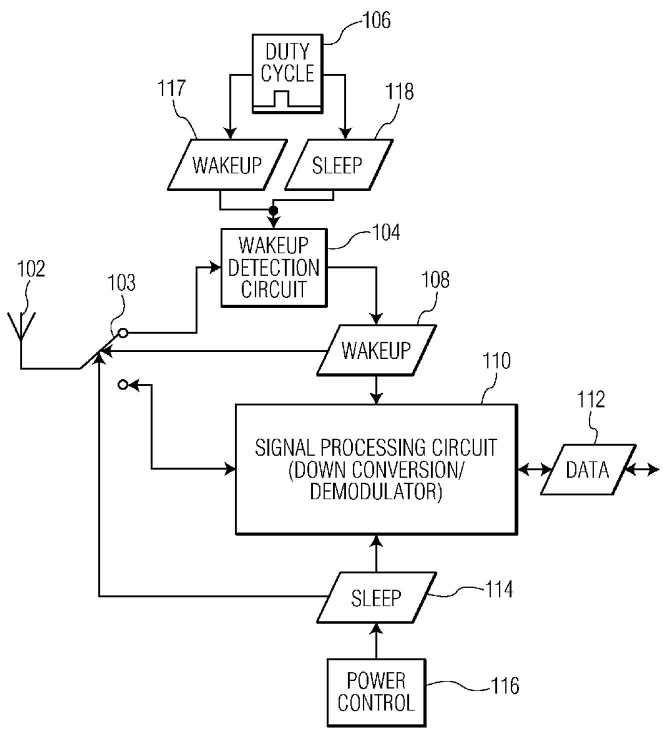

FIG. 1

(57) Abstract: Disclosed are wakeable wireless communications devices, and methods for waking wireless communications devices, for use in a wireless network of such devices. The devices communicate during respectively-designated timeslots according to a communications protocol. The wireless devices include a wireless transceiver that communicates over the wireless network during device-designated timeslots, and that is operative in a reduced power mode during other timeslots. The wireless devices further include a wakeable wakeup detection circuit (106), synchronous with the device- designated TDMA timeslots to transition out of a reduced power mode, to detect valid signals during at least one of the device-designated TDMA timeslots and, in response thereto, to prompt (108) the wireless transceiver to transition out of its reduced power mode and communicate over the wireless network.

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WIRELESS COMMUNICATIONS DEVICE WAKEUP METHOD AND SYSTEM

The present invention relates generally to implementing a wakeup scheme in a plurality of networked wireless devices.

Wireless Sensor Networks (WSNs) include autonomous devices (often referred to as nodes) that are spatially distributed to collect data from the environment and to deliver them to the final user. For self-powered wireless sensors, reducing power consumption can be an important design constraint. A node typically sends and receives a packet of hundreds of bits in a period ranging from seconds to some minutes. Consequently, for nodes that do not reduce power consumption during idles states, the biggest fraction of the energy in each node is spent in idle listening to the channel (e.g., waiting for packets). Other key aspects are the reduced size and the very small cost of the nodes, which directly lead to the need of a complete integration of components into the nodes.

Various aspects of the present invention are directed to methods and arrangements for implementing processor power state transitions in a manner that addresses and overcomes the above-mentioned issues.

Consistent with an example embodiment, the present invention is directed to a wireless device for use in a wireless network having wireless devices communicating during respectively-designated timeslots according to a TDMA protocol. The wireless device includes a wireless transceiver that communicates over the wireless network during designated timeslots according to the TDMA, and that is operative in a reduced power mode during other timeslots. The wireless device further includes a wakeable wakeup detection circuit, synchronous with the device-designated TDMA timeslots to transition out of a reduced power mode, to detect valid signals during at least one of the device-designated TDMA timeslots and, in response thereto, to prompt the wireless transceiver to transition out of its reduced power mode and communicate over the wireless network.

Consistent with another example embodiment, the present invention is directed to a wireless device for use in a wireless network having multiple such wireless devices that communicate using a TDMA protocol. The wireless device includes a wireless transceiver having an active mode for communicating and a reduced power mode, a signal processing circuit for processing communications, and a wakeup detection circuit. The wakeup detection circuit is regulated by a duty cycle so that the wakeup detection circuit is responsive to a device wakeup request during a timeslot in which the wireless transceiver is allowed by the TDMA protocol to receive communications. The wakeup detection circuitry prompts the wireless transceiver to transition from the reduced power mode to the active mode in response to the device wakeup request.

Consistent with another example embodiment, the present invention is directed to a method for use in a wireless network having multiple wireless devices that communicate using a TDMA protocol, each wireless device having a wakeup signal detection circuit. The method includes placing a wireless device in a reduced power mode, duty-cycling the wakeup signal detection circuit so that the wakeup signal detection circuit monitors for a device wakeup request during timeslots in which the wireless device is allowed by the TDMA protocol to receive communications, and in response to the wakeup signal detection circuit receiving the device wakeup request, restoring the wireless device from the reduced power mode to a communications power mode.

The above summary of the present invention is not intended to describe each embodiment or every implementation of the present invention. Advantages and attainments, together with a more complete understanding of the invention, will become apparent and appreciated by referring to the following detailed description and claims taken in conjunction with the accompanying drawings.

The invention may be more completely understood in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

FIG. 1 is block diagram of a wireless device in accordance with an embodiment of the present invention; and

FIG. 2 is a timing diagram illustrating duty-cycling of a wakeup detection circuit radio within a synchronized communications environment in accordance with the present invention.

While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the scope of the invention including aspects defined by the appended claims.

The present invention is believed to be applicable for use with a variety of different Wireless Sensor Networks (WSNs), and particularly to low power WSNs such as Body Area Networks (BAN), and to those for which small form factors can be desirable. While the present invention is not necessarily limited to such applications, an appreciation of various aspects of the invention can be gained through a discussion of examples in such an environment.

The present invention is directed to on-demand waking up of wireless communication devices, and advantageously permits the device receivers to reside in reduced power mode while still being able to monitor for signals. In essence, the device receiver, while residing in a reduced power mode, is able to decide when to turn itself on to listen for communications, and when communications are present, to prompt a full power-up of the device. This can be implemented by having a wakeup detection circuit monitor for a full device wakeup request, and monitor on a scheduled basis to permit the wakeup detection circuit to reside in a reduced power mode when monitoring is not required.

As such, in an exemplary embodiment the present invention can provide power reduction by duty-cycling wakeup detection circuitry so that the wakeup detection circuitry is asleep during periods where no communications are expected and wakes up to listen for data communications when data communications are expected (i.e., when the device is allowed to received data in accordance with a Time Division Multiple Access, or TDMA, protocol). Advantageously, by synchronizing the duty-cycle of the wakeup detection circuit with allowed data reception timeslots, methods and devices of the present invention can promote cost efficiencies by avoiding the need to use high accuracy clocks. Additionally, because the wakeup detection circuit is only listening during timeslots where communications are expected, the power consumption and sensitivity restrictions on the wakeup detection circuit can be relaxed.

Consistent with one embodiment of the present invention, a wireless communication device is implemented as part of a wireless network. The communication device has a wireless transceiver and signal processing circuit for communicating to other devices in the wireless network, for example according to a TDMA protocol. The communications device is placed into a reduced power mode. A wakeup signal detection circuit is also placed into a reduced power mode, and is powered up periodically according to a duty cycle. The duty cycle is timed to wake up the wakeup signal detection circuit during the timeslots in which the wireless device is allowed to receive communications. When the wakeup signal detection circuit is powered up, it monitors for the presence of data to be received and processed. When the wakeup signal detection circuit detects a device wakeup request, signaling that a data packet is being transmitted, the wakeup signal detection circuit prompts the wireless communications device to transition from the reduced power mode to the powered-up communications mode so that the data can be properly received and processed.

FIG. 1 shows a block diagram of a wireless device for use in a wireless network according to an example embodiment of the present invention. Antenna 102 receives transmissions from a wireless network of devices. Switch 103 can be optionally implemented to selectively connect antenna 102 to either wakeup detection circuit 104 or to signal processing circuit 110. The switch 103 is responsive to the power state of the signal processing circuit 110. In sleep (reduced power) mode, the switch connects antenna 102 to wakeup detection circuit 104. In wakeup (active communications) mode, the switch connects antenna 102 to signal processing circuit 110. In some instances, no switch is necessary as the antenna can be connected to both wakeup detection circuit 104 and signal processing circuit 110 at the same time. In some other instances, the wakeup detection circuit 104 and the signal processing circuit 110 can share some building blocks such as a low noise amplifier (LNA).

Wakeup detection circuit 104 has sleep and wakeup modes that are regulated by duty cycle 106. Duty cycle 106 can alternately provide wakeup calls 117 to power up detection circuitry 104 into a monitoring mode, and sleep calls 118 to place detection circuitry 104 in a reduced power mode. Duty cycle 106 can be synchronized with a TDMA protocol so that the wakeup detection circuit 104 is operated in wakeup mode only when data packets are allowed to be received. When in wakeup mode, wakeup detection circuit 104 is responsive to whether data is being communicated to the device for processing. The presence of communicated data is seen by the wakeup detection circuit as a device wakeup request. When the device wakeup request is received, the wakeup detection circuit prompts a wakeup call 108, transitioning the signal processing circuit 110 to a powered-up communications mode so that it can receive and process data 112. When data has been correctly received, the power control unit 116 can trigger a sleep call 114 that transitions the signal processing circuit back into reduced power mode. When the timeslot for receiving data has expired, the duty cycle unit 106 can trigger a sleep call 118 that transitions the wakeup detection circuit back into sleep mode.

During the timeslot allotted for the device to receive communications, the wakeup detection circuit 104 is responsive to device wakeup requests that signal the presence of data to be received and processed. A device wakeup request can be presented in any suitable format, for example as a preamble in the data packet. Presenting the device wakeup request as a preamble in the data packet can afford the wakeup detection circuit 104 sufficient time to trigger a wake up of the signal processing circuit 110 before the data in the data packet is actually received, thereby minimizing potential data loss.

The time lines in FIG. 2 can be used to exemplify a wakeup control scheme of a wireless sensor network in accordance with the present invention. As shown in FIG. 2, time is divided into fixed slots, designated Slot 1, Slot 2, Slot 3, and Slot 4, which form the basis of the TDMA protocol. Accordingly, in each slot only a particular node is allowed to receive data packets, for example time Slot 2 can be allocated to Node 2, time Slot 3 can be allocated to Node 3, and so on, although any desired time division can be used. Any node can transmit a packet in any slot depending on the desired recipient node of the data packet. As exemplified in FIG. 2, Node 3 sends a data packet P to Node 2 in time Slot 2. The duration of the transmission of the data packet P is indicated by T_{pkt}.

In addition to the timeslots for receiving data at respective nodes, there can be specialized timeslots used for time synchronization of the whole network, labeled in FIG. 2 as synchronization beacons B_{sync}. All nodes listen to the synchronization beacons and reset their internal clocks at the reception of the beacon. A particular node, called the master, has the task of periodically sending the synchronization beacon. The duration of the reception timeslots should be long enough to account for timing errors between the clock of the receiver node and the clock of the transmitter node to help ensure that a packet is transmitted when the recipient node is listening to the channel. Since the node clocks are reset at the reception of the synchronization beacons, timing errors in receivers and transmitters are accumulated from the last synchronization beacon, and will depend on clock accuracy. Most of the energy is spent in idle listening to the channel at the receiving node, as opposed to transmitting the packet from the transmitter node since the packet transmission time is usually much shorter than the listening time. In accordance with the present invention, the idle listening energy is reduced by turning on the receiving node's radio only when a packet is going to be received.

Under a TDMA framework, the wakeup detection circuit can remain in a reduced power sleep mode until being turned on in accordance with its duty cycle during the timeslot designated for the node to receive communications. In FIG. 2, the duration of the power-up portion of the duty cycle for the wakeup detection circuit for Node 2 is indicated by T_{WU2}, and the duration of the power-up portion of the duty cycle for the wakeup detection circuit for Node 3 is indicated by T_{WU3}. When a wakeup detection circuit is turned on, it monitors for the presence of a data packet to determine whether to power up the signal processing unit. So that data is not lost during the period between initial detection of the data packet by the wakeup detection circuit and powering up of the signal processing unit, data packets can be provided with a preamble that is used as the device wakeup request, but that is otherwise not processed. In addition or in the alternative, redundancy can be built into the data packet. Duty-cycling of the wakeup detection circuit in concert with the TDMA protocol reduces the energy spent listening to the channel, and relaxes constraints on power consumption.

While not indicated in FIG. 2, the power-up portions of the duty cycles for the wakeup detection circuits for each of the nodes can also include the time period over which the synchronization beacon is expected. As such, receiving the synchronization beacon can be handled in the same manner as for any other communication, except that the wakeup detection circuits for all nodes can be activated to monitor for the synchronization beacon communication.

For those applications where it is desirable to achieve a small form factor while maintaining relatively low energy consumption, the present invention can enable the use of a lower accuracy timing reference implemented with a fully integrated clock generator. Because only the wakeup detection circuit is listening to the communications channel during the node's receiving timeslot, the power consumption in listening mode is reduced. As such, the allowed skew between clocks is relaxed, and fully integrated clocks, which can have accuracies of greater than 5000 ppm, can be used. Moreover, since the power budget for the wakeup detection circuit is increased by duty-cycling, the wakeup detection circuit does not need narrow bandwidth channel filtering, and it can be completely integrated without any components other than the ones available in standard integrated circuit technology, with a consequent beneficial effect on costs.

If low accuracy clocks are employed, the duration of the receiving slots and, consequently, the listening period of the nodes, can be relatively long. As an example, if the clock accuracy is 1%, the synchronization beacon period and the duration of reception slots can be 10 s and 400 ms, respectively. Assuming that the synchronization beacons occupy a temporal slot equal to the reception slots and a node needs to have a reception slot at least once per minute, the wakeup detection circuit would have a duty cycle of 4.67% and the fraction of total average power due to a 500 μW wakeup detection circuit would be only 23.4 μW. With these numbers, assuming a power consumption for the clock of 50 μW, the average power consumption for this approach is 73.4 μW, which is below typical energy constraints for low power consumption WSNs. As the clock requirement on accuracy is relaxed, it can be completely integrated and very low power. Thus, even if the clock is always running, the whole system can remain power efficient.

The various embodiments described above and shown in the figures are provided by way of illustration only and should not be construed to limit the invention. Based on the above discussion and illustrations, those skilled in the art will readily recognize that various modifications and changes may be made to the present invention without strictly following the exemplary embodiments and applications illustrated and described herein. For instance, applications other than microprocessors may be amenable to implementation using similar approaches. In addition, one or more of the above example embodiments and implementations may be implemented with a variety of approaches, including digital and/or analog circuitry and/or software-based approaches. The above example embodiments and implementations may also be integrated with a variety of circuits, devices, systems and approaches including those for use in connection with cellular phones, laptop computers and handheld computing devices. These approaches are implemented in connection with various example embodiments of the present invention. Such modifications and changes do not depart from the true scope of the present invention that is set forth in the following claims.

What is claimed is:

1. For use in a wireless network having wireless devices communicating during respectively-designated timeslots according to a TDMA protocol, a wireless device comprising:

a wireless transceiver to communicate over the wireless network during device-designated timeslots according to the TDMA and operative in a reduced power mode during other timeslots; and

a wakeable wakeup detection circuit (104), synchronous with the device-designated TDMA timeslots to transition out of a reduced power mode, to detect valid signals during at least one of the device-designated TDMA timeslots and, in response thereto, to prompt (108) the wireless transceiver to transition out of its reduced power mode and communicate over the wireless network.

2. The device of claim 1, further including a synchronization circuit that provides synchronization with the device-designated TDMA timeslots.

3. The device of claim 2, wherein the synchronization circuit is a duty cycle unit that provides a wakeup call to the wakeup detection circuit when the device-designated TDMA timeslots open and that provides a sleep call to the wakeup detection circuit when the device-designated TDMA timeslots close.

4. The device of claim 1, wherein the device is further responsive to a synchronization beacon that periodically resets an internal clock of the device along with internal clocks of the other wireless devices of the wireless network.

5. A wireless device for use in a wireless network having multiple such wireless devices that communicate using a TDMA protocol, the device comprising:

a wireless transceiver having an active mode for communicating and a reduced power mode;

a signal processing circuit (110) for processing communications; and

a wakeup detection circuit (104) regulated by a duty cycle (106) so that the wakeup detection circuit is responsive to a device wakeup request during a timeslot in which the wireless transceiver is allowed by the TDMA protocol to receive communications, the wakeup detection circuitry prompting the wireless transceiver to transition from the reduced power mode to the active mode (108) in response to the device wakeup request.

6. The device of claim 5, wherein the device wakeup request is a preamble to a data packet intended for the device.

7. A method for use in a wireless network having multiple wireless devices that communicate using a TDMA protocol, each wireless device having a wakeup signal detection circuit (104), the method comprising:

for each wireless device,

placing the wireless device in a reduced power mode (114);

duty-cycling (106) the wakeup signal detection circuit so that the wakeup signal detection circuit monitors for a device wakeup request during timeslots in which the wireless device is allowed by the TDMA protocol to receive communications; and

in response to the wakeup signal detection circuit receiving the device wakeup request, restoring the wireless device from the reduced power mode to a communications power mode (108).

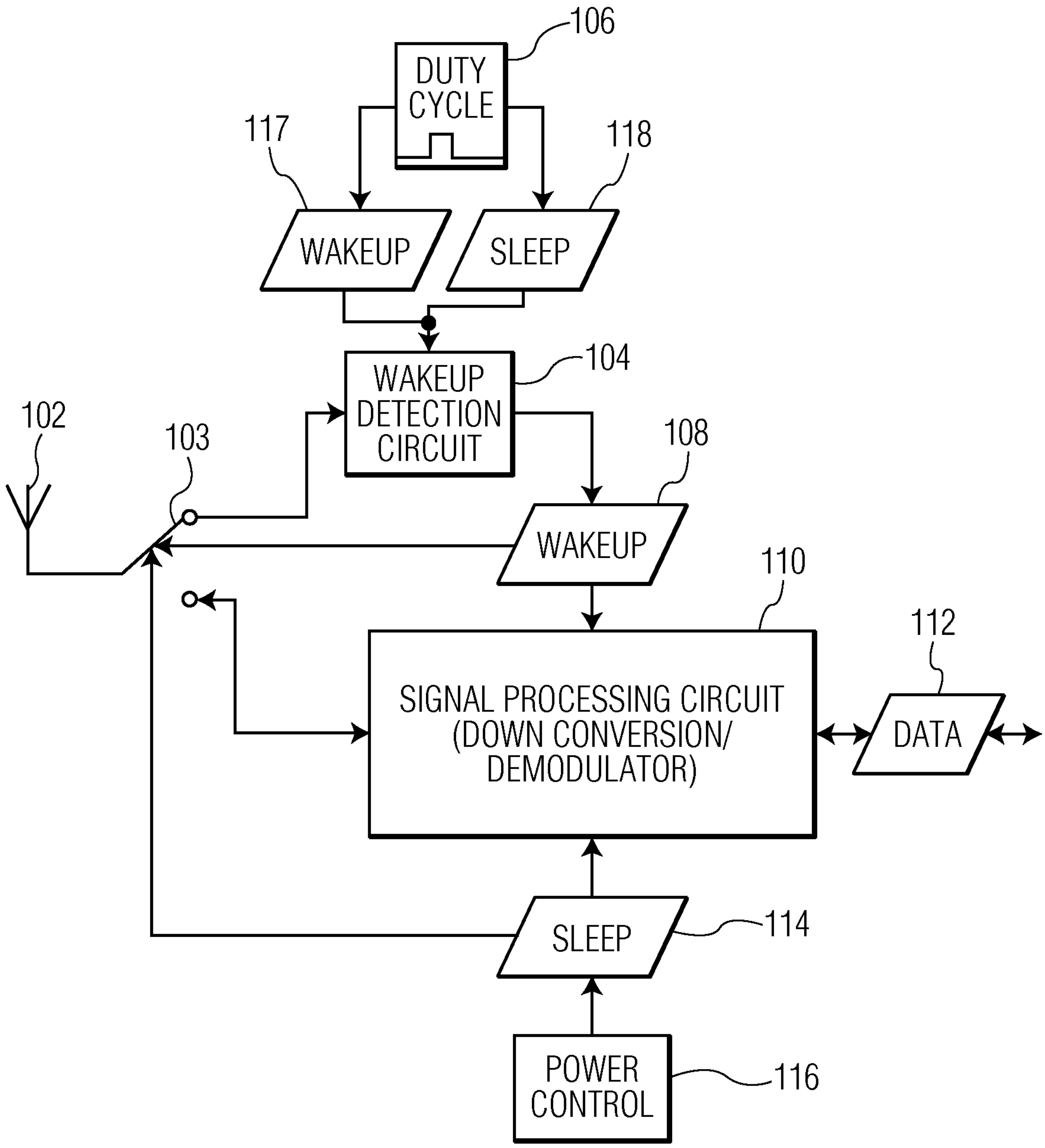
106
DUTY CYCLE
117
118
WAKEUP
SLEEP
WAKEUP DETECTION CIRCUIT
104
102
103
108
WAKEUP
110
SIGNAL PROCESSING CIRCUIT (DOWN CONVERSION/ DEMODULATOR)
112
DATA
SLEEP
114
POWER CONTROL
116

FIG. 1

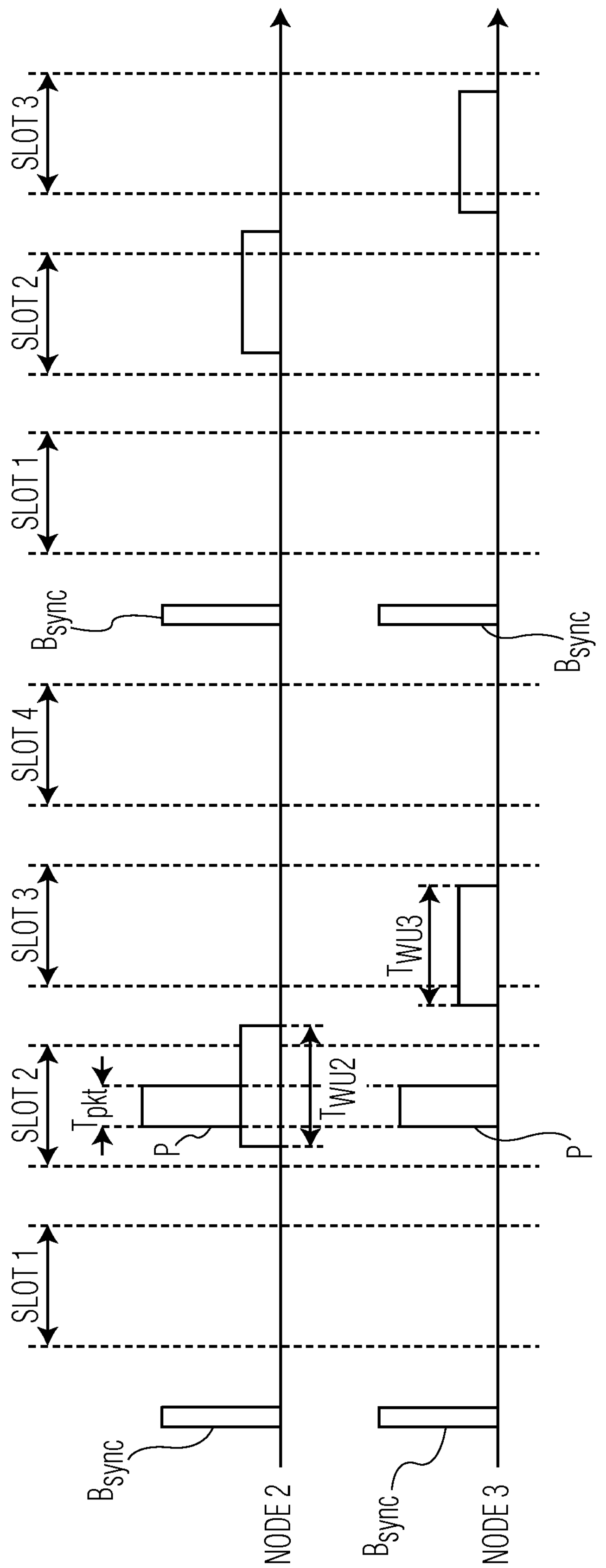
SLOT 3
SLOT 2
SLOT 1
Bsync
SLOT 4
SLOT 3
SLOT 2
SLOT 1
Bsync
TWU3
Tpkt
TWU2
P
P
Bsync
Bsync
NODE 2
NODE 3

FIG. 2