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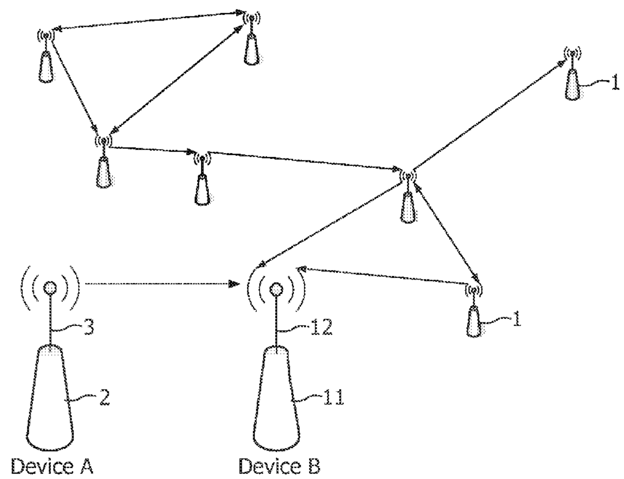
(54) Title: DEVICE DISCOVERY IN A LOW POWER WIRELESS SYSTEM



(57) Abstract: A communications protocol is described for particular applicability to wireless low-power devices that can only operate according to a duty cycle. The protocol increases the speed at which two devices 2,11 in a network 1 may be synchronized, while minimising the power consumption of the devices 2,1 1. The protocol involves the transmission of a plurality of polling words by a transmitter 3 to a receiver 12, and determination by the receiver 12 that a polling word has been transmitted to it during a sensing period. The determination results from the receiver 12 periodically listening for a polling signal during the sensing period. The receiver 12 is thus arranged so that it is able to detect a polling word transmitted over a period of time for part of which the receiver 12 is idle.

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DEVICE DISCOVERY IN A LOW POWER WIRELESS SYSTEM

FILED OF THE INVENTION

The present invention relates to the field of wireless communications, and in particular, but not exclusively, to low power radio devices such as those powered by a battery.

BACKGROUND OF THE INENTION

In a small and/or inexpensive battery-powered wireless transceiver module it may be that the battery is so small that it is unable to provide sufficient peak current to supply the transceiver, or that its average current capacity is less than that required for continuous operation of the transceiver. A solution to this problem is to use a capacitor as an energy storage element. The battery charges the capacitor and then when it is sufficiently charged the transceiver can be powered up and operate for a short time until the capacitor discharges. In this scenario the transceiver can only function according to a regular duty cycle. Figure 1 illustrates an example of such a duty cycle, for a resistive-capacitive charge system, and a constant current discharge. For a charge time T_{off} and a discharge time T_{on}, the transceiver duty cycle is calculated by the ratio $\frac{T_{on}}{T_{on}+T_{off}}$. Other charge/discharge methods can be used, which will affect the duty cycle accordingly.

The maximum duty cycle of a transceiver (or any circuit) operated in this way is governed by a number of factors including the peak current available from the power source, the peak current required by the circuit, maximum and minimum voltages required at the input and output of the charge/discharge circuit, and charge/discharge mechanism.

The main problem with a wireless transceiver that has a limited power supply is that the transceiver cannot communicate continuously with another device, so the two devices need to be synchronised to communicate effectively. Device discovery (the process of one device first becoming aware of another device) is therefore a particular problem because the new device's transmitter cannot continually send a polling signal until it is discovered, as its capacitor may drain before discovery. If the transmitter can only transmit intermittently and the existing device's receiver only listens for polls intermittently, it could take a very long time (T_{sync}) for discovery to take place. If a device wishing to discover another simply turns on its receiver for as long as it can before draining its capacitor, and if its charge time is much greater than the transmission period of the device wishing to be discovered, it could be a very long time before the receiver happens to be operational when the latter device is transmitting, wasting power in both the transmitter and receiver.

The power consumption for receive and transmit modes can be assumed to be similar so both will operate in the aforementioned duty cycle mode. Figure 2 shows a typical timing sequence for synchronization between a transmitting device A and a receiving device B. The receive cycle of device B is arranged to have a fractionally lower duty cycle than that of device A to ensure that synchronization ultimately occurs as a result of the relative phase shift between the transmit and receive cycles. The difference between the duty cycles is not so large that a receiver could miss two transmission sequences in between listening attempts. The duty cycle can be reduced by increasing the charging period of device B. In figure 2, the simple example where the discharge times for both devices are equal, T_{on}, is shown.

It can be shown that for a synchronization scheme as shown in figure 2, the synchronization time, T_{sync}, is given by

$$T_{sync} \leq \left(\frac{1}{DutyCycle_A} + 1 \right) T_{NetworkA} \qquad (1)$$

where device A has a duty cycle $DutyCycle_A$ and a network period of $T_{Network\,A}$ equal to $T_{off\,A} + T_{on\,A}$. The derivation of inequality (1) is contained in the Appendix.

The expression above indicates that the synchronization time is dependent on the nature of the transmission signal, in the case where the discharge times of the two devices are equal. The expression also shows that there is a trade-off which may be made between a desired synchronization time, and power consumption (related to the duty cycle), which may be optimised according to specific applications. In low-power applications where rapid synchronization is required, there is therefore a need to reduce the average time it will take for a device to be discovered, while maintaining power consumption at a low level.

In practice, the lack of an intelligent protocol in the scheme shown in Figure 2 can lead to a potentially long synchronization time, as the receiver has limited knowledge of the timing of the signal which it is attempting to receive. The assumption of equal T_{on} periods for transmission and reception modes cannot always be made. Correlation between a transmission mode and a reception mode may simply result from a chance co-incidence.

This synchronization problem has been addressed in a number of ways. For example, United States Patent US 6,697,649 proposes the use of clocks which are internal to network devices, these clocks being periodically resynchronised. A second solution is to use an external clock, but both of these solutions require costly and complex implementation. A third solution is to use a detection circuit which responds to a transmission from a network node to bring a device out of sleep mode. This solution may still result in a long synchronization time, however, involving transmission or reception for long periods, which is power-inefficient. United States Patent Application US 2003/0016732 discusses a technique for device discovery that uses transmission at pseudo-random timeslots and frequencies to attempt to generate chance co-incidences of transmission and reception, which would lead to a decreased synchronization time. In the absence of a well-defined protocol however, this solution is highly inefficient.

SUMMARY OF THE INVENTION

The present invention aims to provide an improved communication protocol which will enable a reduced device synchronization time between devices, while being power-efficient.

According to a first aspect of the present invention there is provided a radio communications system including a transmitter and a receiver, in which the transmitter is configured to intermittently transmit a polling signal comprising a sequence of polling words to the receiver, there being a plurality of listening periods during which the receiver is configured to listen for a polling word, or a plurality of polling words, transmitted by the transmitter, each listening period being separated by an idle period during which the receiver is not configured to listen for a polling signal, the listening and idle periods forming a sensing period and being so arranged that a plurality of pollingwords can be sensed by the receiver at any time during the sensing period, the transmitter and receiver being further arranged to be synchronized when the receiver senses a polling word transmitted by the transmitter.

According to a further aspect of the present invention, there is provided a method of discovering a device in a radio communications system comprising a transmitter and a receiver, including the steps of the transmitter intermittently transmitting a sequence of polling words to the receiver, the receiver sensing that a polling signal has been transmitted to it during a sensing period, and synchronization of the transmitter and receiver upon the receiver sensing that a polling word has been transmitted to it during a sensing period, wherein a sensing period comprises a plurality of listening periods during which the receiver listens for a polling signal, and each listening period is separated by an idle period during which the receiver does not listen for a polling signal, the listening and idle periods so arranged that a polling signal, a word of which is transmitted to the receiver at any time during the sensing period, can be sensed by the receiver.

Synchronization is made quicker in the present invention by using a transmission and reception protocol which enables a receiver to efficiently attempt to detect a signal from another transmitter. The protocol effectively enables the receive window, or sensing period of a device in discovery mode to be increased, to increase the likelihood of receiving a transmission signal during the window, but in such a way that there is a limited power penalty associated with the receiving mode.

Preferably, the receiver is periodically to have an idle period which is shorter than the duration of transmitted sequence of polling words. This ensures that the sensing period is such that a polling signal can be received across its full duration, and also minimises the time for which the receiver must be operational in order to achieve this, thereby saving power.

Preferably, the listening period has a duration of at most twice the period of a transmitted polling word. By limiting the operation of the receiver in this way, the associated power use of the receiver can be similarly limited.

Further optional features are as set out in the dependent claims.

The techniques of the present invention may have applications for any part of the Medium Access Control (MAC) protocol in a wireless transceiver where there is a requirement for extended transceiver operation in an embodiment where the power source is not capable of delivering the required peak power. Typical examples may be in RFID tag systems, or Near Field Communication systems (NFCs).

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows the operating duty-cycle of a device used in an embodiment of the present invention;

Figure 2 shows a standard synchronization scheme for two devices operating at different duty cycles;

Figure 3a shows the network topology of an embodiment of the present invention;

Figure 3b shows a schematic representation of the transmitter and the receiver of an embodiment of the present invention;

Figure 4 shows a simplified transmission sequence used in an embodiment of the present invention;

Figure 5 shows the listening period of the receiver used in an embodiment of the present invention;

Figure 6 shows the receiver operation modes used in an embodiment of the present invention;

Figure 7 shows a sensing period of the receiver in an embodiment of the present invention;

Figure 8 shows how the protocol of embodiments of the present invention lead to reduced device synchronization time; and

Figure 9 shows an example of a successively time-shifted shifted receive window with respect to a transmission cycle.

DETAILS OF THE INVENTION

In an embodiment of the present invention, there are wireless devices within a communications network, or wishing to join a communications network, whose topology is shown in Figure 3a. In this figure there are two devices 2,11 – device A that wishes to be discovered, and device B which is attempting to discover another device. The network comprises a plurality of transceiver nodes 1 each of which is capable of either transmission or reception of data, or a combination of both, to other nodes in the network.

Figure 3b shows a schematic representation of devices A and B used in the network of figure 3a. Device A contains a wireless transmitter 3 for transmitting a polling signal to alert other devices to its presence. The transmitter 3 transmits a signal, generated by a signal generator 4, via wireless Radio Frequency (RF) communication as is well-known in the art. The signal generator 4 is an RF signal transmitter, and is controlled by a control means such as a Central Processing Unit (CPU) 5, which operates in accordance with the communication protocol described below. The protocol is programmed as an algorithm stored in a memory means such as a Read Only Memory (ROM) (not shown) of the CPU 5. The CPU 5 also has overall control of the transmitter 3.

Device B contains a receiver 12, which during a discovery period is arranged to listen for polls transmitted by other devices. The receiver 12 can be switched on and off by a control means, again a CPU 13 operating in accordance with the communication protocol described below. A ROM (not shown) stores the receiver algorithm for the CPU.

In the simplest embodiment of the invention, transmitter 3 in device A transmits at a single pre-defined radio frequency and receiver 12 in device B listens at that same frequency. In this scenario, the devices are aligned in frequency and must then achieve discovery in time. However, the invention can be extended to situations in which the transmitter 3 and receiver 13 transmit and receive at a plurality of frequencies, as is well-known in the art. Then device discovery must be achieved in frequency as well as in time and will therefore take longer.

Device B also contains a correlation module 14 for correlating a received transmission signal with an expected transmission from another device. The correlation module 14 comprises means (not shown) for being programmed to anticipate a particular transmission signal. Reception of a desired transmission signal is preferably indicated by a correlation peak, or other positive indication means, generated in the correlation module 14, which indicates successful correlation above a certain threshold, which in turn indicates successful reception of an expected transmission. Upon successful correlation, two way communication occurs between the two devices, in a synchronized manner. The two-way communication involves a data exchange from data memories (RAMs) 6,16 in the two devices. A modulator (not shown) is incorporated into the signal generator 4 for the purposes of data transmission and a demodulator 15 is used in the device B to demodulate received data into a form suitable for storage in the storage means 16.

Both devices have power supplies of the form discussed above, using a battery 7,17 and a capacitor 8,18 as a storage element. A switch 9,19 under control of an oscillator 10,20, switches each of the devices from charge mode (in which the switch 9,19 connects the battery 7,17 to the capacitor 8,18) to a discharge mode, in which each device is powered by the capacitor 8,18. The capacitors 8,18 discharge through the resistance of the circuitry. The frequency of the oscillators 10,20 is controlled by the CPU 5,13 in each device.

In this embodiment, device A sends out a polling signal comprising a sequence of polling words until its capacitor 8 is drained. It then switches off to recharge the capacitor 8. Each polling word, hereinafter referred to as a poll, is a multiple-bit sequence, such as a 13-bit sequence, divided into predetermined fields, the arrangement of which is known to device B, so that communication between the two devices may be initiated upon reception of a polling word by device B. Preferably, one of the fields of the poll includes the address of device A. Alternatively, device identification between devices A and B can take place later, after discovery, during the device synchronization phase. Additionally, one of the fields can contain the number of the poll, starting at one for the first poll and then incremented for each successive poll, as this can aid device synchronization following discovery.

A transmission sequence used in this embodiment is shown in Figure 4. The transmitter 3 of device A transmits a sequence of n polls, each poll having a duration of T_{poll}. The transmission time is thus nT_{poll}. Figure 4 shows the transmission sequence containing a sequence of adjacent polls, but the bitstreams within the polls are not shown. The transmitter 3 then switches off so that device A can recharge its capacitor 8 from battery 7, over period $T_{recharge}$.

Device B turns on its receiver 12 to listen for long enough to receive a single poll, of duration T_{poll}. This receive length is defined as the listening period T_{rxon}. In the worst case scenario, used in this embodiment, T_{rxon} needs to be equal to $2T_{poll}$ to ensure that if device B starts receiving just after the beginning of a poll transmitted by device A, it will successfully receive all of the following poll (assuming of course that device B did not miss the last poll of the nT_{poll} transmission sequence).

Figure 5 shows how such an arrangement allows the successful reception of a second poll, transmitted by device A, once the first poll has been missed by device B.

If device B successfully receives a poll, synchronization with device A is achieved, as discussed later in this description.

After an unsuccessful attempt to receive a poll, device B switches off its receiver 12 for an idle period T_{rxoff}. As device B knows that device A will only poll for a total time of nT_{poll}, it can wait for a period of up to $nT_{poll} - T_{poll}$ before switching its receiver 12 back on, without missing the next possible time when device A might be polling. Figure 6 shows a worst-case scenario in which device B has just missed the first poll transmitted by device A. By switching off its receiver 12 for time $nT_{poll} - T_{poll}$, device A is able to receive the last poll in the same sequence of polls transmitted by device A while minimising the time for which it is attempting to receive a poll.

Reception attempts are made periodically by device B, according to the time periods T_{rxon} and T_{rxoff} until the capacitor 18 of device B requires recharging. Since T_{rxon} and T_{rxoff} have been chosen to ensure that a poll will not be missed, if indeed one is transmitted by device A before the recharging period of the capacitor 18 of device B commences, there exists an extended receive window of duration T_{eff}, in which device B can effectively receive a poll, despite the fact that for periods of time T_{rxoff} within the window T_{eff}, the receiver 12 is actually switched off. This period T_{eff} will be referred to as a sensing period, as it is such that a polling signal, a word of which is transmitted at any time during the sensing period, can be sensed by the receiver. In this case, "sensing" means that the receiver can determine that the polling signal has been transmitted, whether it is in listening mode or idle mode.

The form of such a sensing period is illustrated in Figure 7. Figure 8 demonstrates two examples and compares them to the standard case to show how the reduction in synchronization time is achieved by using the extended receive window described herein. It should be noted that in practice device A stops transmitting polling signals after device synchronisation is achieved and does not continue indefinitely as depicted in Figure 8.

It is possible to derive an expression for the synchronization time, T_{sync}, for a system using the above protocol. The derivation is based on a consideration of the relative phases of the transmit and receive windows.

After each transmission cycle, the relative phase between the transmit and receive windows is shifted from its relationship at the end of the previous cycle, due to the fact that the cycles are of different period (the same principle as illustrated in figure 2). The amount by which the phase relationship is shifted can be expressed as a time period T_{shift}. Since the receive cycle has a longer period (due to the extended receive window as described above), the receive cycle will lag behind the start of a transmit cycle by a further T_{shift} than the time difference which was present at the time of the previous transmission.

T_{shift} can be defined as the time difference between a receive cycle and a transmission cycle, so that at the end of a transmission cycle, the receive cycle lags the transmission cycle by a further T_{shift} than at the end of the previous cycle. A receive cycle has a period of [T_{eff} + $T_{recharge}$] and a transmission cycle has a period of [nT_{poll} + $T_{recharge}$], therefore:

$$T_{shift} = T_{eff} - nT_{poll}$$

With reference to Figure 9, the worst case synchronisation instance is when the receiver activates just after the end of the poll from the transmitter. Synchronisation will occur when the position of the sensing window has shifted enough (with respect to the position of the transmitter's poll) that it overlaps by at least T_{poll} (the minimum amount of time required to achieve synchronisation). This can be described mathematically by:

$$\alpha T_{shift} \geq T_{recharge} - (T_{eff} - T_{poll})$$

where α represents an integer multiple of T_{shift} to achieve synchronisation.

Combining the above two equations we get:

$$\alpha \geq \frac{T_{recharge} - T_{eff} + T_{poll}}{T_{eff} - nT_{poll}}$$

To get the minimum synchronisation time, we take the next highest integer i.e.:

$$\alpha = \left\lceil \frac{T_{recharge} - T_{eff} + T_{poll}}{T_{eff} - nT_{poll}} \right\rceil \quad (2)$$

α gives the number of time shifts that have occurred to achieve synchronisation in the worst case example shown in Figure 9. There have therefore been α +1 cycles of the transmitter polling sequence so the worst case synchronisation time is given by the following expression:

$$T_{sync} \leq (\alpha + 1)(nT_{poll} + T_{recharge}) \quad (3)$$

The formulae given above allow a basic comparison to be made between the standard synchronization scheme and the extended window scheme described above. Results are highly dependent on the application, but the figures used in the two examples below are derived from the same experimental system.

For the standard synchronization scheme, the synchronization time is given by:

$$T_{sync} \le \left(\frac{1}{DutyCycle_A} + 1 \right) T_{NetworkA} \qquad (1)$$

as derived in the Appendix and discussed above.

Using T_{on} = 6.44ms and T_{off} = 0.5s, which leads to a transmitter duty cycle of 0.012716 and a network period of 0.50644s, substitution into the inequality (1) gives $T_{sync} \le$ 40.33276 seconds.

Using the extended window scheme, the synchronization time is given by inequality (3), as derived above.

The same transmission sequence is used as above, where $T_{on} = nT_{poll}$. For a 13-bit poll transmitted at 50000bps, such this gives T_{poll} = 0.00026s, and n = 24.76923.

The effective receive window, T_{eff} is calculable from the exponential charge and linear discharge characteristics of the power supply used in the application, but simulation greatly facilitates this calculation. In this example, simulation was used to obtain a value of T_{eff} = 0.302s. Substitution into equation (3) leads to $\alpha = \lceil 0.671 \rceil = 1$.

Substitution into expression (2) above leads to $T_{sync} \le 1.013$s.

The above calculations demonstrate a clear improvement in performance from the extended window scheme.

In the embodiment described above, T_{rxon} is equal to $2T_{poll}$, as a worst case in terms of power consumption. T_{rxon} may be shortened so that device B turns on and attempts to receive part of a poll. Only if it receives a detectable signal, distinguishable above the noise level, does device B continue to listen for the full polling word, otherwise it switches off. This technique further reduces power consumption.

In order to ensure that the effective receive window is actually “effective”, it is necessary that the period T_{rxon} is such the entire duration of a desired polling signal, which may be a portion of a full polling word, can be detected. As discussed, there is an upper limit on T_{rxon}, because a period which is longer will simply result in power wastage in the receiver 12 – the effective window enables detection of synchronization across its whole duration.

The second requirement for ensuring that the receive window is effective is that there is an upper limit on the T_{rxoff} periods, to ensure that entire polling signals are not missed. Therefore, T_{rxoff} must be shorter than the duration of a transmitted sequence of polls. Shortening the idle periods will have the same effect as increasing the listening period, as discussed above, for a given receiver network period ($T_{rxon} + T_{rxoff}$).

As demonstrated in Figure 8, the speed of synchronization of devices A and B may be varied by controlling the width of the sensing period. This may itself be achieved by optimising the number of listening attempts possible before recharging becomes necessary, for example, by enabling recharging of the receiver 12 during non-listening periods T_{rxoff}. It may be possible for the sensing period to extend indefinitely, which would give the minimum synchronization time possible, if the capacitor can be fully recharged during the period T_{rxoff}. In such a case, separate recharging periods would not be required between sensing periods.

A variety of protocols may be used, with which device B responds to device A upon synchronization so that 2-way communication may begin. In one embodiment of the present invention, device B hears part of a polling signal (it can listen to several polls in order to improve correlation accuracy). Before device B responds to device A it must wait till the end of the polling signal when device A switches from transmission to reception. This can be achieved by device B listening for continued transmission of the polling sequence, or by device B listening intermittently for continued transmission of the polling sequence, or by device B waiting for a period of $n.T_{poll}$ when it is guaranteed that device A will have stopped transmitting, or by having each poll containing a field within it that gives the poll number so that if n is known the number of polls left is known and so the time till the end of the polling signal is known. Having waited until the end of the polling signal it then waits for a further random back-off time before responding with an acknowledgement signal. The acknowledgement allows device A to recognise device B and then at a defined time start 2-way communication. The random-backoff period is a random positive integer r multiplied by the length of the acknowledgement sequence (of length T_{ack}). This allows several new devices to join the network, or connect with the polling device, at the same time without clashing with each other. Device A needs enough power to transmit for nT_{poll} and then receive for rT_{ack}. The number r is a trade-off between how many devices might be discovered simultaneously and the amount of time that can be spent trying to receive an acknowledgement. The longer rT_{ack}, the shorter nT_{poll} can be.

In an alternative embodiment, device B could respond to device A whilst device A is still transmitting, if device A is a duplex transceiver that can transmit and receive at the same time, as is well-known in the art.

It should be noted that this protocol is not restricted to having a device transmitting for $n.T_{poll}$ while the other receives for T_{eff}. It is also possible to reverse the roles of the devices so that the receiver is operational for $n.T_{poll}$ and the transmitter for T_{eff} in exactly the same manner of pulsed operation as described above.

A more sophisticated charging scheme could be used that provides a constant, rather than non-constant resistive-capacitive, current charge to the capacitors 8,18. If the power supply of each device is capable of operating in such a way, the duty cycles could be increased, which would reduce discovery time.

Another possibility for an embodiment is to have the capacitor constantly being trickle charged, while only being discharged intermittently. This has the effect of reducing the discharge current from the capacitor and therefore offering longer active periods before the device returns to its low power mode.

The devices described are so-called “actively-powered” devices in which a battery is used as the main power source. It is possible for the capacitor to form part of a passively-powered device, which derives its power from a transmission signal, using a standard diode arrangement when receiving a.c. signals.

It is not compulsory for the devices to contain energy-storage capacitors. The devices can simply be powered by batteries alone, under the control of switches, which could be recharged by radiation techniques or the like. References to “recharging” above would then refer to the recharging of the batteries of the devices.

The signal generator could generate a polling signal according to any suitable modulation scheme, including high order modulation schemes to enable shorter polls in the time-domain. The modulation scheme could be adaptable or be different for the device discovery, device synchronisation or normal data communication phases. In each case, the clock frequency of the transmitter determining the bit rate of the polling signal and the clock frequency of the receiver 12 must be equated as far as possible, to ensure that the receiver 12 is capable of detecting part of a polling signal at a particular frequency. Possible clock drift should be taken into account by reducing the idle periods of the receiver to avoid missing the polling word, as would be clear to anyone skilled in the art. A polling word may be simpler or more complex than the 13-bit arrangement described.

Polling may also be performed on more than one frequency channel. In such an application, the need for efficient device discovery is even greater due to the fraction of power which must be assigned to frequency-sweeping operations, and the benefit of the invention is therefore increased.

To increase the accuracy of the correlator, correlation on a plurality of polls can be performed. In the correlation peak detection technique described above, a plurality of correlation peaks could be detected by correlation on a plurality of poll and these peaks averaged or combined in some manner to increase the likelihood of detection. The correlation module 14 could be implemented as a software algorithm running on a microprocessor, or could be implemented in hardware which typically would be a matched filter and comparator circuit.

As an addition to the correlation technique, a relative signal strength indication (RSSI) measurement could be taken to determine the presence and strength of a polling signal. The RSSI measurement could then be compared with a threshold value to determine whether the receiver 12 should continue listening, and attempting correlation, or to switch off because there is apparently no signal being transmitted. This technique reduces receiver power consumption.

Timings within devices are typically measured using frequency references that are subject to certain tolerances. Adjustments must therefore be made to the precise values to ensure synchronisation can still be achieved given the components in use, as evident to those skilled in the art.

In the embodiments described above, systems with two devices have been described. Such a system may be a sub-set of a wider communications network, comprising a number of network devices or transceiver nodes. In the embodiments described, a device operating in receive mode may be a device existing in the network at a time when a new device, or transmission source external to the network wishes to be discovered, so that it may join the network. Alternatively, the transmitter 3 may be an existing network device. Issues such as transmitter or receiver power consumption will decide which protocol is most appropriate for a given network.

The transmitting device 2 and receiving device 11 shown in figure 3a are simplifications of network devices – each device may comprise both transmission and reception modules under the control of a processor. Each device may be capable of processing data stored in its data storage means internally, for example for display purposes, or calculations to be performed on the data by the node. Conversely, simple devices which are capable solely of transmission, such as a beacon, or solely of reception, such as a terminal, may be employed, according to the particular application. In the case of transmission beacon, the transmitter may not necessarily comprise a data storage means, the transmitter simply transmitting a hardcoded device address, for example.

The use of the word “transceiver” in the above description should be interpreted sufficiently broadly as to cover each of these examples.

It is of course possible to extend the communications protocol described above to networks where a plurality of devices wish to be discovered. In such a situation, the multiple frequency polling and multi-level transmission schemes may be appropriate, to enable each device to communicate with a plurality of others. Such communication may be used in a network where individual transceiver nodes act as routers of network traffic. A device may receive information from one node and forward it to another. Alternatively, the two devices A and B described above may exist in isolation from a wider network of nodes, simply requiring synchronization with each other in order to perform a particular task.

The protocol described is applicable to wireless communication devices other than radio devices, for example optical devices.

Although claims have been formulated in this application to particular combinations of features, it should be understood that the scope of the disclosure of the present invention also includes any novel features or any novel combination of features disclosed herein either explicitly or implicitly or any generalisation thereof, whether or not it relates to the same invention as presently claimed in any claim and whether or not it mitigates any or all of the same technical problems as does the present invention. The applicants hereby give notice that new claims may be formulated to such features and/or combinations of such features during the prosecution of the present application or of any further application derived therefrom.

APPENDIX

Derivation of inequality (1) (See figure 2):

Consider the situation where *x* sequences of polling words are transmitted by the transmitter A before synchronization occurs. The receiver B is operating at a fractionally longer duty cycle, and consequently the first instance of synchronization will occur after *(x–1)* listening periods of the receiver.
Thus:

$$T_{sync} = xT_{NetworkA} = (x-1)T_{NetworkB} \qquad \text{(A1)}$$

Now assume $T_{onA} = T_{onB}$ so that $T_{NetworkB} = T_{onA} + T_{offB}$ where T_{on} and T_{off} represent the active and inactive periods of the device respectively; and the postfixes represent the Device (A or B) as indicated in Figure 2.
For the purposes of this derivation, let synchronization occur when any portion of the transmission sequence overlaps with any listening attempt by B. Since B is operating at a longer duty cycle, such that $T_{offB} \geq T_{offA} + T_{onA}$, substitution into the above leads to:

$$T_{NetworkB} \geq 2T_{onA} + T_{offA}$$

$$\Rightarrow \quad T_{NetworkB} \geq T_{onA} + T_{NetworkA} \qquad \text{(A2)}$$

Therefore, substitution of (A2) into (A1) gives:

$$xT_{NetworkA} \geq (x-1)[T_{onA} + T_{NetworkA}] \qquad \text{(A3)}$$

By definition, $DutyCycle_A = {T_{onA}}/{T_{NetworkA}}$ and from (A1), $x = {T_{sync}}/{T_{NetworkA}}$.

Substitution into (A3) leads to:

$$xT_{NetworkA} \geq (x-1)[DutyCycle_A T_{NetworkA} + T_{NetworkA}] = (x-1)T_{NetworkA}[DutyCycle_A + 1]$$

$$\Rightarrow \quad T_{sync} \geq [{T_{sync}}/{T_{NetworkA}} - 1]T_{NetworkA}[DutyCycle_A + 1]$$

$$\Rightarrow \quad T_{sync} \geq [T_{sync} - T_{NetworkA}][DutyCycle_A + 1]$$

$$\Rightarrow DutyCycle_A T_{sync} \leq [DutyCycle_A + 1]T_{NetworkA}$$

$$\Rightarrow T_{sync} \leq \left(\frac{1}{DutyCycle_A} + 1\right)T_{NetworkA} \qquad \text{Inequality (1)}$$

CLAIMS

1. A wireless communications system including a transmitter and a receiver,

the transmitter being configured to intermittently transmit a polling signal comprising a sequence of polling words to the receiver, and

the receiver being configured to listen for a polling signal transmitted by the transmitter during a plurality of successive listening periods, each separated by an idle period during which the receiver is not configured to listen for a polling signal, the listening and idle periods forming a sensing period and being so arranged that a word of the polling signal that is transmitted to the receiver at any time during the sensing period, can be sensed by the receiver,

the transmitter and receiver being further arranged to be synchronized when the receiver senses a polling signal transmitted by the transmitter.

2. A system according to claim 1 wherein at least one of the transmitter and receiver has a power supply derived from a battery.

3. A system according to claim 1 or 2 wherein at least one of the transmitter and receiver has an energy-storage capacitor to supply power thereto.

4. A system according to claim 3 wherein the transmitter comprises an energy-storage capacitor arranged to be charged by the battery during an interval between transmission of polling signals.

5. A system according to claim 3 or 4 wherein the receiver is arranged to intermittently sense that a polling signal has been transmitted, the receiver being driven by an energy-storage capacitor arranged to be charged by the battery during an interval between sensing periods.

6. A system according to claim 3 wherein the receiver is driven by an energy-storage capacitor which is arranged to be charged during idle periods.

7. A system according to claim 1 wherein at least one of the transmitter and receiver is passively powered.

8. A system according to any preceding claim wherein a listening period of the receiver is extended on receipt of a signal from the transmitter forming part of a polling word, so that the receiver can receive the entire polling word.

9. A system according to any preceding claim wherein each idle period is of shorter duration than the sequence of polling words.

10. A system according to claim 9 wherein the sequence comprises a predetermined number of polling words and each idle period is equal to the duration of one less than said predetermined number of polling words.

11. A system according to any preceding claim wherein each listening period is of duration of at most twice the period of a polling word.

12. A system according to any preceding claim wherein transmission of a polling signal during a sensing period is sensed by means of a relative signal strength indication (RSSI) measurement.

13. A system according to claim 12 wherein a listening period is extended if an RSSI measurement is greater than a threshold.

14. A system according to any of claims 1 to 11 wherein successful reception of a polling signal during a sensing period is achieved using a correlator that correlates on polling words contained within the polling signal.

15. A system according to claim 14 wherein successfulreception of a polling signal during a sensing period is based on a plurality of correlation peaks produced by the correlator correlating with a plurality of correlation words.

16. A system according to any preceding claim wherein at least one of the transmitter and receiver can communicate with a plurality of transmitters or receivers simultaneously.

17. A system according to any preceding claim wherein the receiver is arranged to transmit an acknowledgement sequence to the transmitter, on sensing a polling signal transmitted by the transmitter.

18. A system according to claim 16 wherein the receiver is arranged to transmit the acknowledgement sequence after and within a predetermined time period.

19. A transceiver comprising a transmitter and a receiver for use in the communications system of any of claims 1 to 18.

20. A network of transceiver nodes wherein at least one node comprises the transmitter or receiver of claims 1 to 18 or a transceiver according to claim 19.

21. A method of discovering a device in a wireless communications system comprising a transmitter and a receiver, including the steps of:

the transmitter intermittently transmitting a sequence of polling words to the receiver;

the receiver sensing that a polling signal has been transmitted to it during a sensing period; and

synchronization of the transmitter and receiver upon the receiver sensing that a polling signal has been transmitted to it during a sensing period, wherein a sensing period comprises a plurality of listening periods during which the receiver listens for a polling signal, and each listening period is separated by an idle period during which the receiver does not listen for a polling signal, the listening and idle periods so arranged that a polling signal, a word of which is transmitted to the receiver at any time during the sensing period, can be sensed by the receiver.

22. A transceiver comprising a transmitter and a receiver operating according to the method of any of claim 21.

23. A Medium Access Control (MAC) layer of a wireless transceiver according to claim 22.

24. A network of transceiver nodes wherein at least one node comprises the transmitter or receiver operating according to the method of claims 21 or a transceiver according to claim 22.

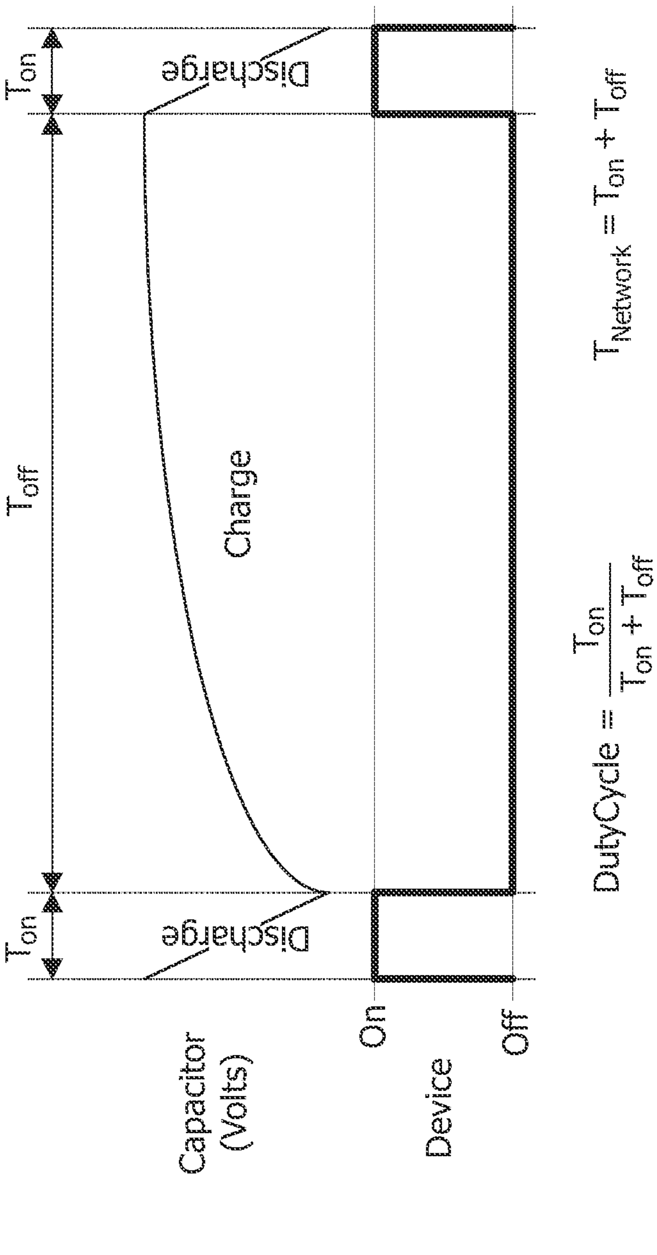

Capacitor (Volts)
Device
On
Off
Ton
Toff
Ton
Discharge
Charge
Discharge
DutyCycle = Ton / (Ton + Toff)
TNetwork = Ton + Toff

FIG. 1

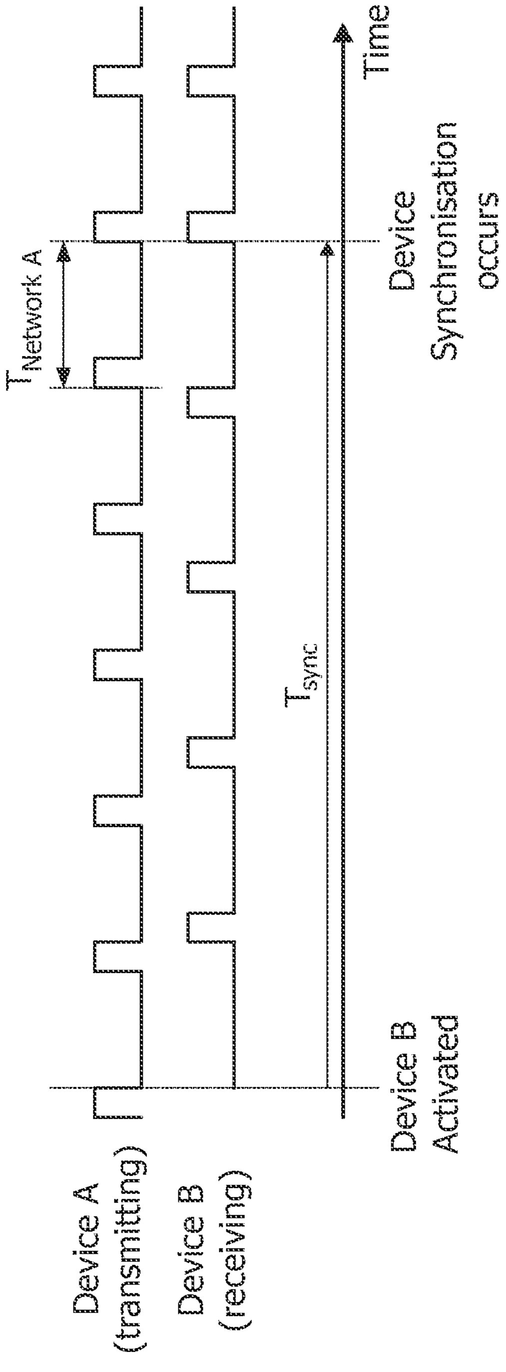

Device A (transmitting)
Device B (receiving)
$T_{Network A}$
T_{sync}
Time
Device B Activated
Device Synchronisation occurs

FIG. 2

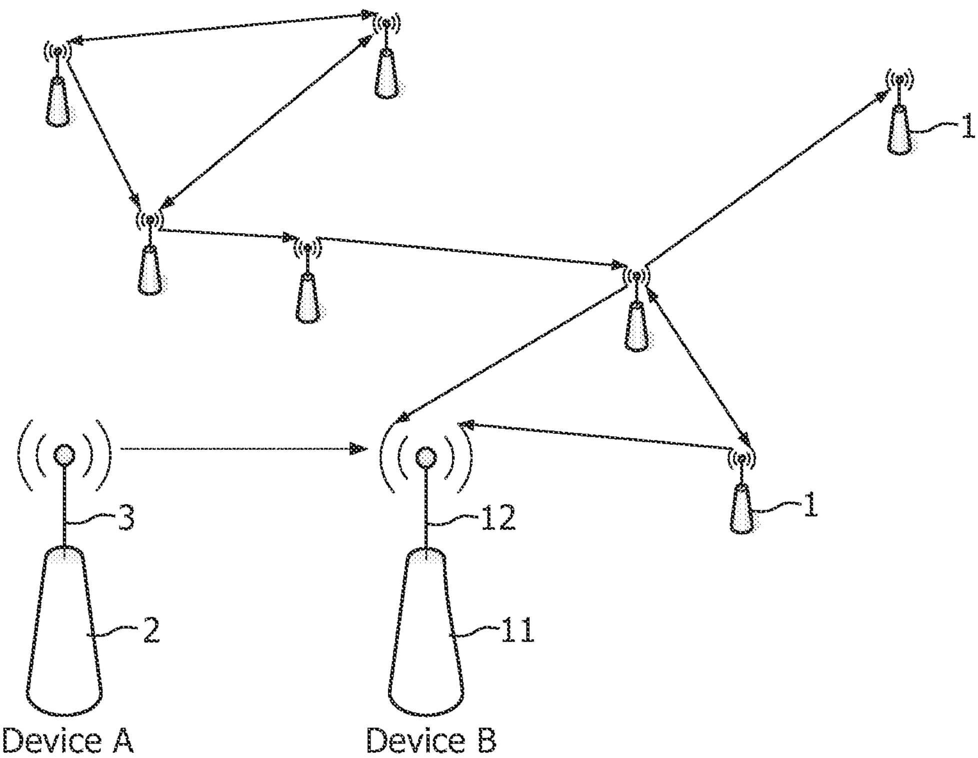


FIG. 3a

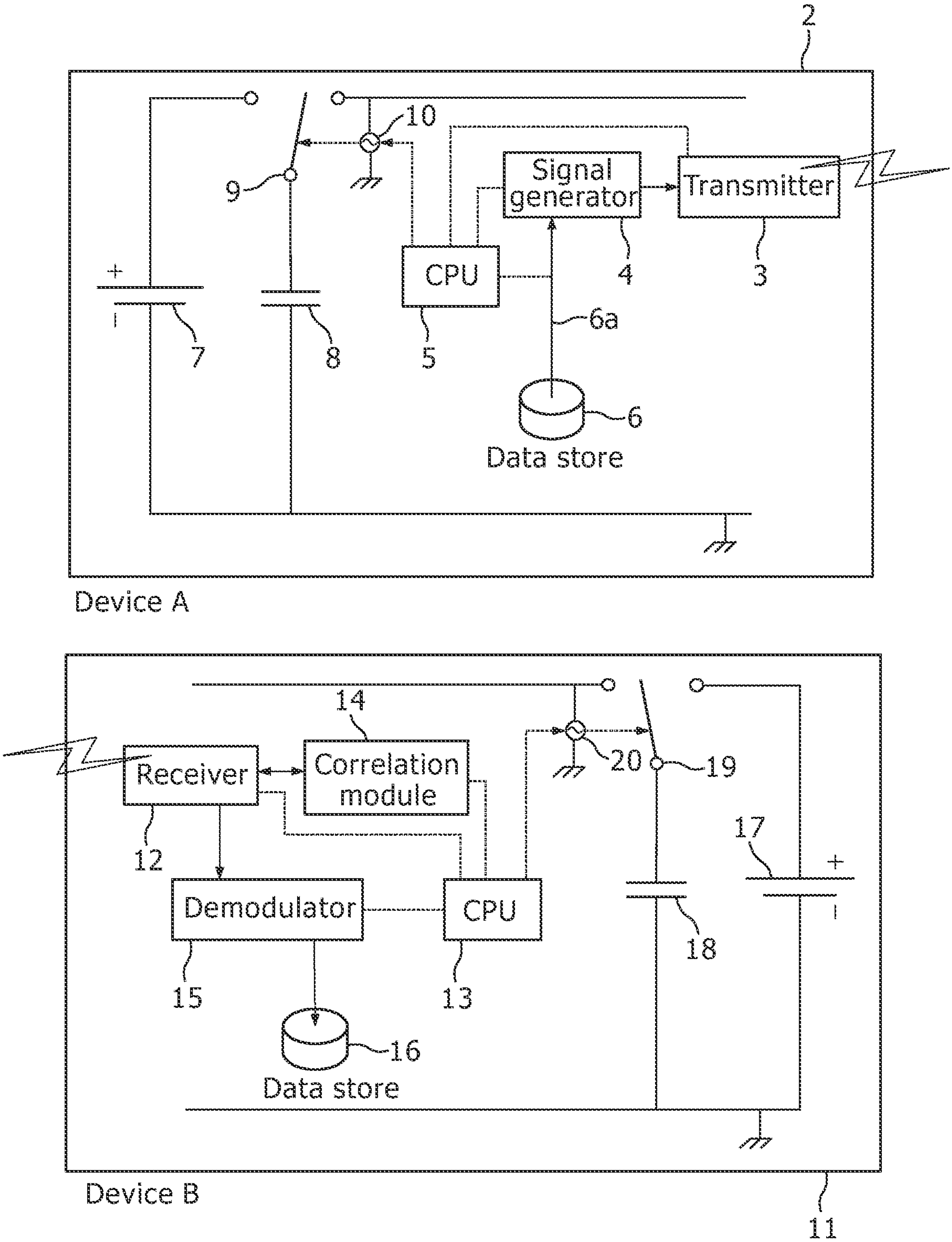

2
10
9
Signal generator
Transmitter
CPU
4
3
+
-
7
8
5
6a
6
Data store
Device A
14
Receiver
Correlation module
20
19
12
17
+
Demodulator
CPU
-
18
15
13
16
Data store
Device B
11

FIG. 3B

FIG. 4

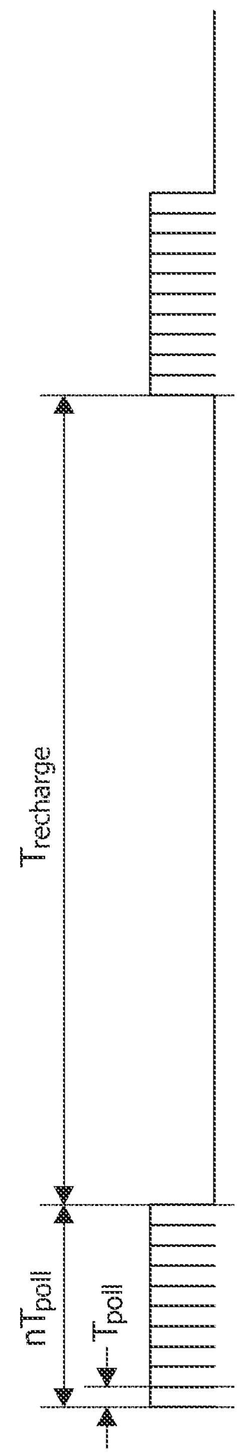
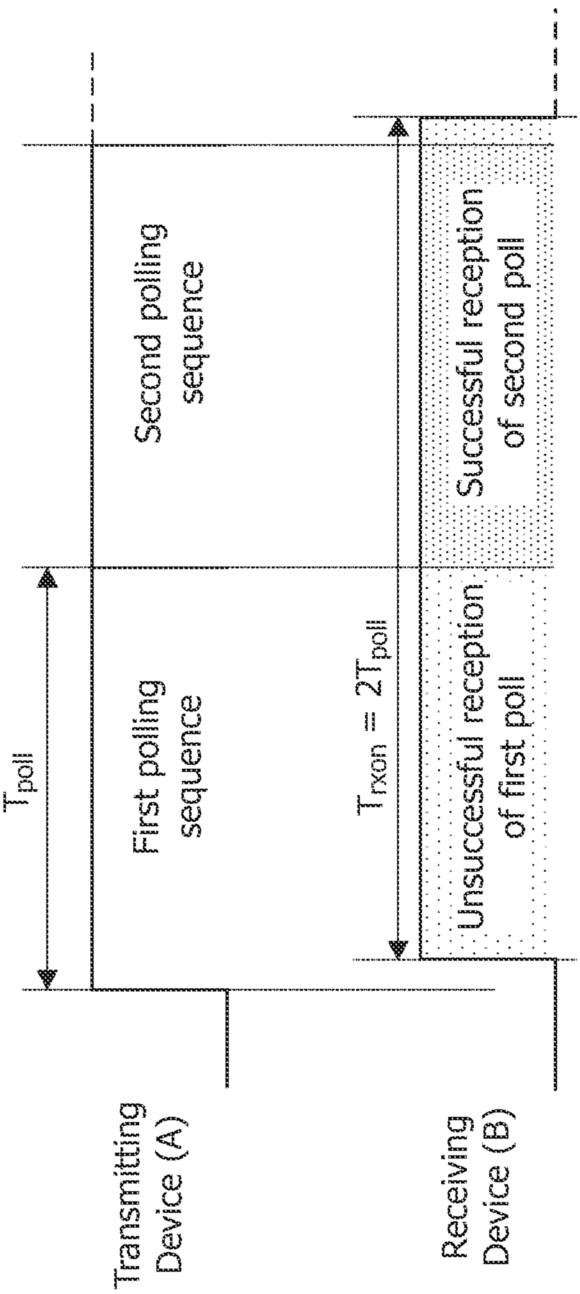

nTpoll
Tpoll
Trecharge

FIG. 5


Transmitting Device (A)
Receiving Device (B)
Tpoll
First polling sequence
Second polling sequence
Trxon = 2Tpoll
Unsuccessful reception of first poll
Successful reception of second poll

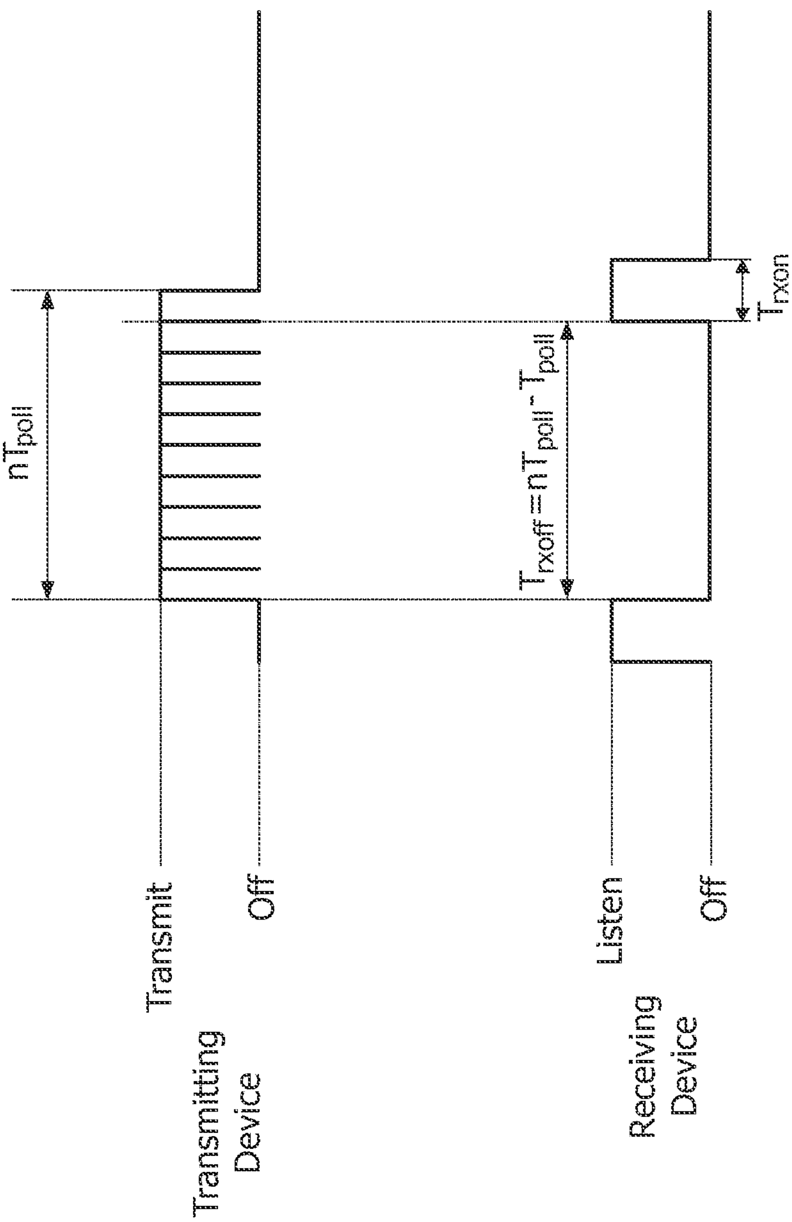

nT_poll
T_rxoff = nT_poll - T_poll
T_rxon
Transmit
Off
Listen
Off
Transmitting Device
Receiving Device

FIG. 6

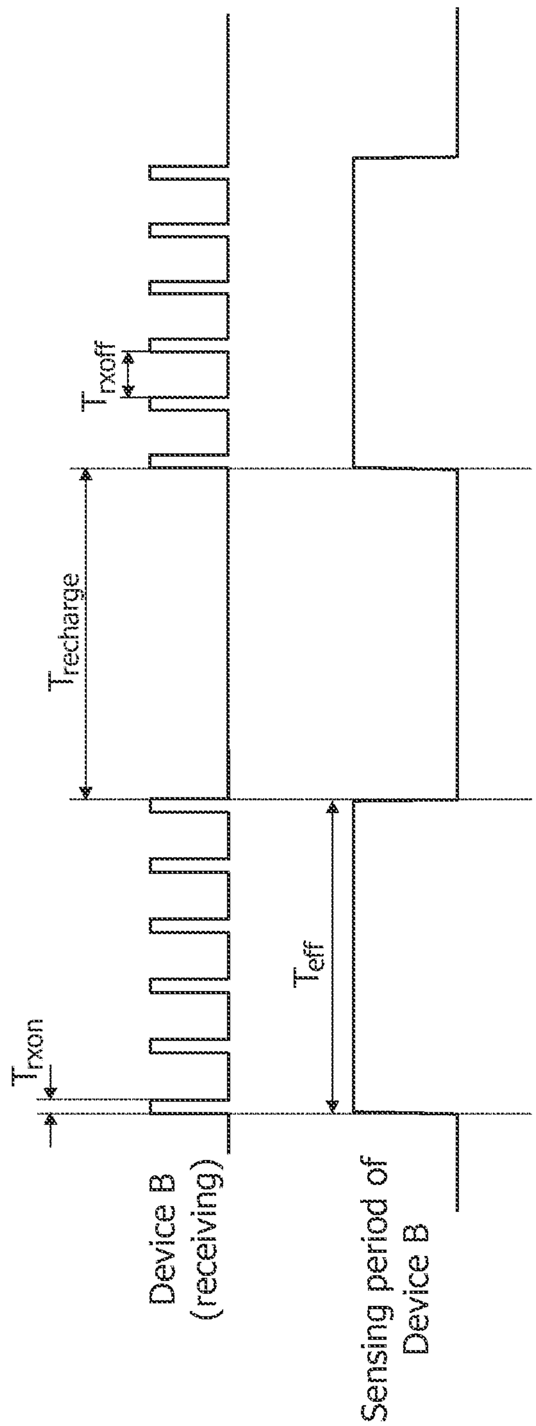

Device B
(receiving)
Sensing period of
Device B
T_{rxon}
T_{rxoff}
$T_{recharge}$
T_{eff}

FIG. 7

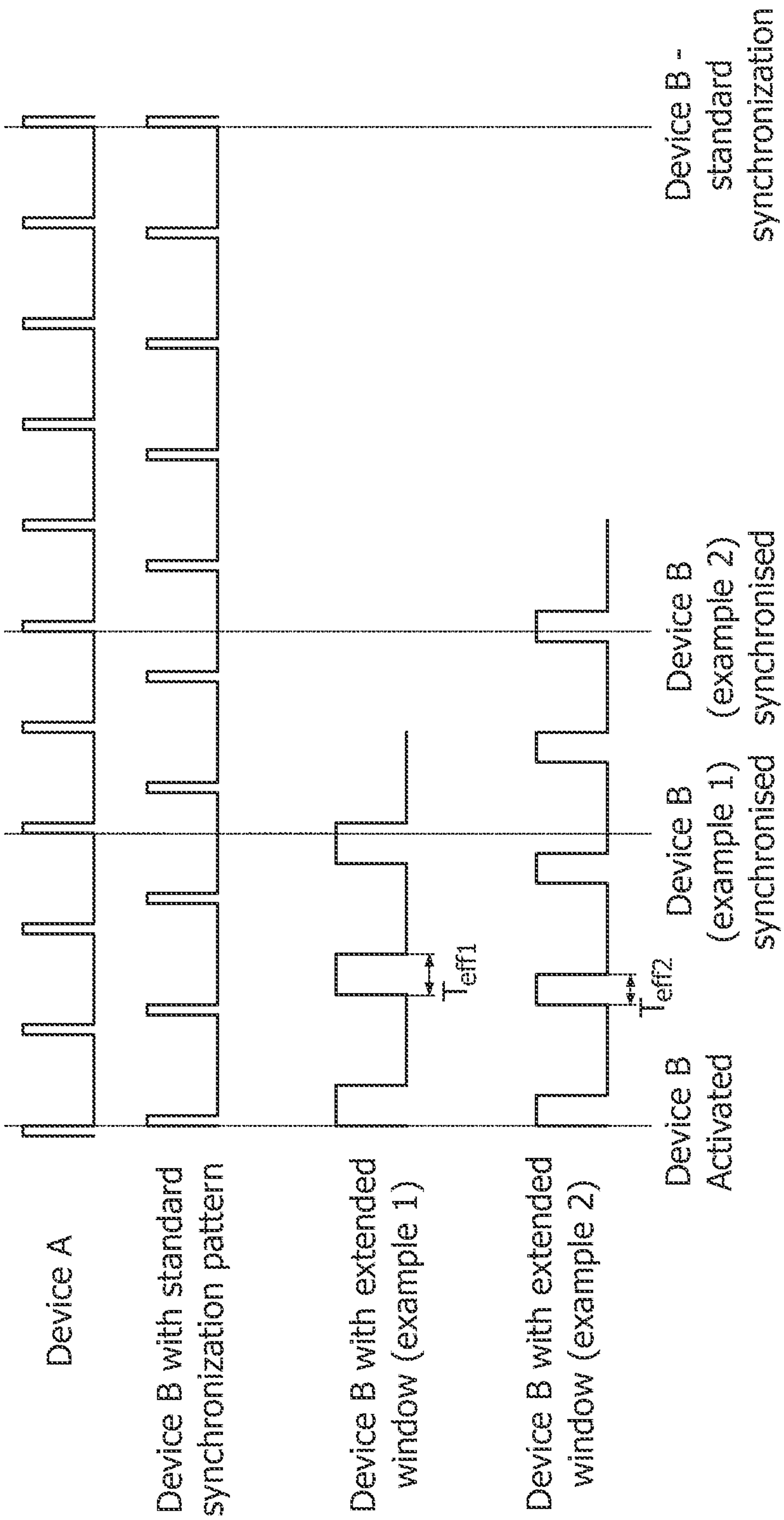

Device A
Device B with standard synchronization pattern
Device B with extended window (example 1)
Device B with extended window (example 2)
Teff1
Teff2
Device B Activated
Device B (example 1) synchronised
Device B (example 2) synchronised
Device B - standard synchronization

FIG. 8

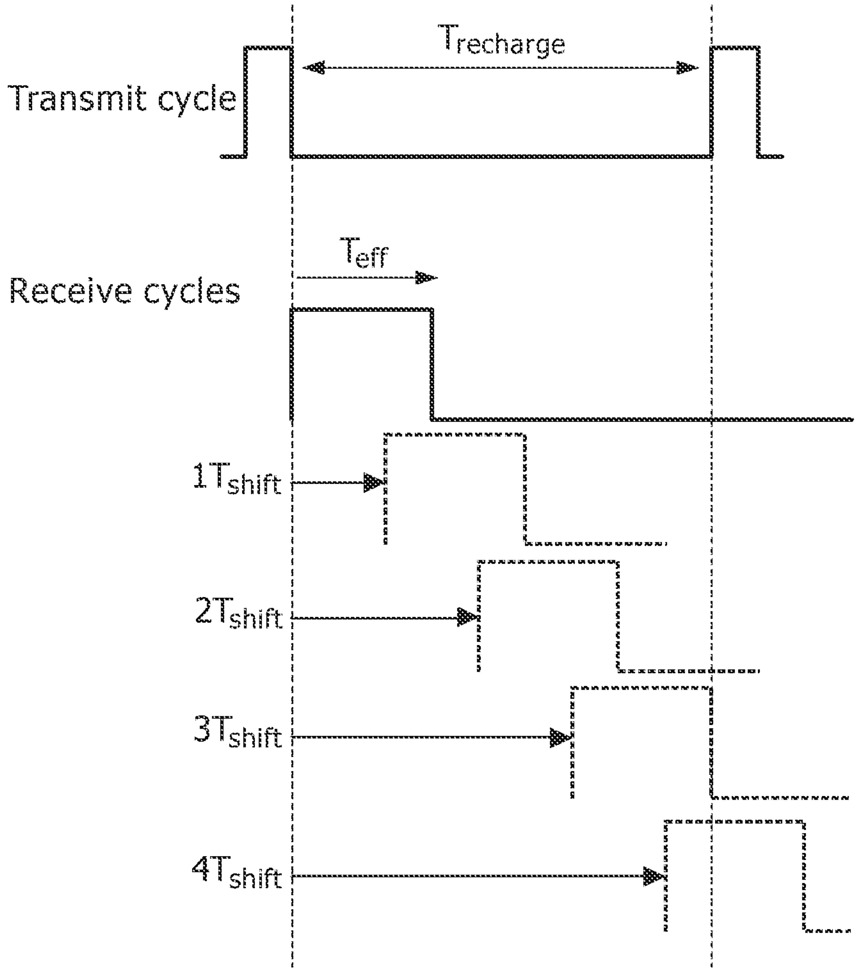

Transmit cycle
Trecharge
Receive cycles
Teff
1Tshift
2Tshift
3Tshift
4Tshift

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2007/050713

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04Q7/32

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04Q H02J H04B G06K

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 560 383 A (STMICROELECTRONICS BELGIUM N V [BE]) 3 August 2005 (2005-08-03) abstract; figure 2 paragraph [0001] paragraph [0003] paragraph [0016] paragraph [0019]	1-6, 17-22,24
A	EP 0 654 911 A2 (NOKIA MOBILE PHONES LTD [FI] NOKIA CORP [FI]) 24 May 1995 (1995-05-24) page 2, line 56 - page 3, line 31	1,3-6, 21,22
X	WO 2005/053248 A (UNIV HERIOT WATT [GB]; RECORD PAUL [GB]) 9 June 2005 (2005-06-09) page 5, line 21 - page 11, line 21 figures 9,11	1,2,14, 15, 19-22,24

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 June 2007	03/07/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Behringer, Lutz

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	EP 1 657 852 A (SONY DEUTSCHLAND GMBH [DE]) 17 May 2006 (2006-05-17) paragraph [0021] - paragraph [0024] figure 1 -----	1,19-24

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2007/050713

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			DE	69432509	T2	26-02-2004
			FI	94685	B	30-06-1995
			JP	3442881	B2	02-09-2003
			JP	7202795	A	04-08-1995
			US	5519711	A	21-05-1996
WO 2005053248	A	09-06-2005	BR	PI0416488	A	13-03-2007
			CN	1883164	A	20-12-2006
			EP	1683312	A1	26-07-2006
			KR	20060126976	A	11-12-2006
			US	2006205421	A1	14-09-2006
EP 1657852	A	17-05-2006	JP	2006148906	A	08-06-2006
			US	2006133408	A1	22-06-2006