A collection of wirelessly networked devices including first devices wirelessly networked together using a first wireless protocol that is a frequency hopping protocol, and second devices wirelessly networked together using a second wireless protocol, are operated in a coordinated manner, including proactive reduction of interference between the networked devices. In one embodiment, the first devices include at least a first and a second subset operating with a first and a second frequency hopping pattern respectively. The proactive reduction effort includes synchronized operations of the first and second subsets of the first devices, and the second devices operate in a manner complementary to the synchronized operations of the first devices. In one embodiment, the collection of wirelessly networked devices includes at least one wireless device that operates in both wireless networks in accordance with both wireless protocols. The multi-protocol device is equipped to at least facilitate prospective anticipation of whether transmission of a long packet that spans multiple ones of successive frequencies by a device of the first wireless network will cause interference with devices of the second wireless network.
FIG. 3

FIG. 4
FIG. 5

FIG. 6
FIG. 8A
$f_x = f_7 = f_{14}$ - CURRENT ACTIVE FOP FREQUENCY OF 802.11

BT HOPPING PATTERN

BT IS NOT ACTIVE AT THESE FREQUENCIES. TX - MASTER TRANSMIT, RX - MASTER RECEIVE

STAND ALONE BT

802.11 ONLY

TX/RX ANY TIME

802.11 ONLY

TX/RX ANY TIME

COLLOCATE 802.11 AND BT TRUE RADIO

TX IN BT MODE  |  RX IN BT AND 802.11  |  TX IN BT MODE  |  RX IN BT AND 802.11

TX IN 802.11 MODE  |  RX IN BT AND 802.11  |  TX IN 802.11 MODE

FIG. 8c
START

DETERMINE PSEUDO RANDOM PATTERN AND INF. FREQUENCY

SELECT DOMINATED DEVICES

INTF. TO OCCUR?

YES → NOTIFY DOMINATED DEVICE TO SUSPEND OPERATION

NO

END OF OPERATION?

YES → END

NO
$f_x = f_7 = f_{14}$ - CURRENT ACTIVE FPP FREQUENCY OF 802.11
TX/RX - TRANSMIT OR RECEIVE MODE

BT HOPPING PATTERN

BT MAY BE ACTIVE AT ANY FREQUENCY AND ANY TIME. APPLY FILTERS AT THESE HOPS

STAND ALONE BT RADIO

802.11 ALONE RADIO

802.11 MAY ALSO BE ACTIVE AT ALL TIME, BUT APPLY FILTERS AT THESE HOPS

COLLOCATE 802.11 AND BT RADIO - TRUE RADIO

TX IN BT MODE  TX IN 802.11 MODE  TX IN BT MODE  TX IN 802.11 MODE

FIG. 10
FIG. 116
FIG. 12
FIG. 13
**Fig. 14**

**Synchronized Networks**

**Subset 1** (e.g., Piconet 1)

**Subset 2** (e.g., Piconet 2)

**Total Time**

**Fig. 15**
SUMMARY OF THE INVENTION

A collection of Tirelessly networked devices including first devices Tirelessly networked together using a first wireless protocol that is a frequency hopping protocol, and second devices Tirelessly networked together using a second wireless protocol, are operated in a coordinated manner, including proactive reduction of interference between the networked devices. In one embodiment, the first devices include at least a first and a second subset operating with a first and a second frequency hopping pattern respectively. The proactive reduction effort includes synchronized operations of the first and second subsets of the first devices, and the second devices operate in a manner complementary to the synchronized operations of the first devices. In one embodiment, the collection of Tirelessly networked devices includes at least one wireless device that operates in both wireless networks in accordance with both wireless protocols. The multi-protocol device is equipped to at least facilitate prospective anticipation of whether transmission of a long packet that spans multiple ones of successive frequencies by a device of the first wireless network will cause interference with devices of the second wireless network.

BRIEF DESCRIPTION OF DRAWINGS

The present invention will be described by way of exemplary embodiments, but not limitations, illustrated in the accompanying drawings in which like references denote similar elements, and in which:

FIG. 1 illustrates an overview of the wireless device of the present invention, in accordance with one embodiment;
FIG. 2 illustrates a period of operation of the wireless devices of FIG. 1, in accordance with one embodiment;
FIG. 3 illustrates the wireless device of FIG. 1 in further detail, in accordance with one implementation;
FIG. 4 illustrates the operational states and flow of the state machine of FIG. 3 in further detail, in accordance with one implementation;
FIG. 5 illustrates the wireless device of FIG. 1 in further detail, in accordance with another implementation;
FIG. 6 illustrates the operational states and flow of the state machine of FIG. 5 in further detail, in accordance with one implementation;
FIG. 7 illustrates the wireless device of FIG. 1 in further detail, in accordance with yet another implementation;
FIGS. 8a–8b illustrate a period of operation of the wireless devices of FIG. 1, in accordance with each of two alternate embodiments;
FIGS. 9a–9b illustrate the architecture and operational flow of the wireless device 100 of FIG. 1 for practicing a selected one of the methods of operation of FIGS. 8a–8b, in accordance with one embodiment;
FIG. 10 illustrates a period of operation of the wireless devices of FIG. 1, in accordance with another embodiment;
FIGS. 11a–11b illustrate the architecture and operational flow of the wireless device 100 of FIG. 1 for practicing the method of operation of FIG. 11, in accordance with one embodiment;
FIG. 12 illustrates the concept of notch filtering;
FIG. 13 illustrates an overview of the wireless device of the present invention, in accordance with another embodiment;
FIG. 14 illustrates another overview of the multi-protocol wireless device of the present invention, along with other wireless devices, in accordance with yet another embodiment; and
FIG. 15 illustrates the concept of synchronized operation of two subsets of devices employing a frequency hopping protocol in accordance with two corresponding frequency hopping patterns.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, various aspects of the present invention will be described. However, it will be apparent to those skilled in the art that the present invention may be practiced with only some or all aspects of the present invention. For purposes of explanation, specific numbers, materials and configurations are set forth in order to provide a thorough understanding of the present invention. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details. In other instances, well known features are omitted or simplified in order not to obscure the present invention.

Parts of the description will be presented using software terminology commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. As well understood by those skilled in the art, these software quantities take the form of electrical, magnetic, or optical signals capable of being stored, transferred, combined, and otherwise manipulated through mechanical and electrical components of a digital system; and the term digital system includes general purpose as well as special purpose processors, systems, and the like, that are standalone, adjunct or embedded.

Various operations will be described as multiple discrete steps performed in turn in a manner that is most helpful in understanding the present invention, however, the order of description should not be construed as to imply that these operations are necessarily order dependent, in particular, the order the steps are presented. Furthermore, the phrase “in one embodiment” will be used repeatedly, however the phrase does not necessarily refer to the same embodiment, although it may.

Referring now to FIG. 1, wherein an overview of the present invention, in accordance with one embodiment, is shown. As illustrated, wireless device 100 is provided with wireless transceivers 102a and 102b to transmit and receive signals wirelessly in accordance with a first and a second wireless communication protocol, to enable device 100 to be communicatively coupled to devices 104a and devices 104b of wireless networks 108a and 108b respectively. Wireless device 100 further includes controller managers 106a and 106b to control the operation of wireless transceivers 102a and 102b respectively. As will be described in more detail below, controller managers 106a and 106b control transmits and receives by wireless transceivers 102a and 102b, in a coordinated manner, in accordance with the present invention, to allow wireless device 100 to operate with devices 104a and devices 104b of wireless network 108a and 108b in accordance with the respective wireless communication protocols at the same time.

In one embodiment, controller managers 106a and 106b control transmits and receives by wireless transceivers 102a and 102b (hereinafter, simply transceivers), in a coordinated manner. More specifically, in this embodiment, controller managers 106a and 106b control transceivers 102a and 102b to alternate between transmits by one of the two transceivers and receives by both of the two transceivers. FIG. 2 illustrates a period of operation in accordance with this embodiment. As shown, in time period T1, for duration T1, control manager 106a controls transceiver 102a to perform transmit of signals to devices 104a of wireless network 108a (hereinafter, simply network) in accordance with the first wireless communication protocol (hereinafter, simply protocol), while control manager 106b controls transceiver 102b to neither perform transmit nor receive of signals to and from devices 104b of network 108b. In time period T2, for duration T2, the reverse is performed. Control manager 106b controls transceiver 102b to perform transmit of signals to devices 104b of network 108b in accordance with the second protocol, while control manager 106a controls transceiver 102a to neither perform transmit nor receive of signals to and from devices 104a of network 108a. In time periods T2 and T4, for duration T2 and T4 respectively, controller managers 106a and 106b control both transceivers 102a and 102b to perform receive of signals from devices 104a and 104b of network 108a and 108b in accordance with the respective protocols respectively.

Since all wireless protocols operate on either a carrier sense or contention free protocol, devices 104a are able to receive in time period T1, and transmit when there are packets to transmit, but otherwise receive, in time periods T2–T4. Likewise, devices 104b are able to receive in time period T3, and transmit when there are packets to transmit, but otherwise receive, in time periods T1–T2 and T4. Accordingly, wireless device 100 is able to operate with devices 104a and 104b of networks 108a and 108b in two wireless protocols at the same time.

Note that time periods T1–T4 may or may not be equal in duration. That is, numerically T1–T4 may or may not be equal. As will be described in more detail below, in different variants of this embodiment, duration T1–T4 of time periods T1–T4 are dynamically and adaptively set. In particular, in some variants, duration T1–T4 of time periods T1–T4 are adaptively set based at least in part in transmit and receive workloads of networks 108a and 108b.

Referring back to FIG. 1, except for the teachings of the present invention incorporated in wireless device 100 to effectuate the above described coordinated manner of operation of transceivers 102a and 102b, transceivers 102a and 102b as well as controller managers 106a and 106b are otherwise intended to represent a broad range of these elements known in the art. Accordingly, except for the teachings of the present invention, which will be further described below, transceivers 102a and 102b and controller managers 106a and 106b will not be otherwise further described.

Wireless device 100 is intended to represent a wide range of devices that can benefit from having the ability to wirelessly operate with other wireless devices in two or more wireless communication protocols at the same time. Examples of device 100 include but not limited to computers of various form factors, such as desktop, notebooks, palm size and so forth, controller devices (i.e., master devices) to manage and control the operation of networks 108a and 108b, and gateway devices to facilitate communication between devices 104a and devices 104b.

Likewise, devices 104a and 104b are intended to represent a broad range of devices that can benefit from being able to communicate wirelessly. Examples of devices 104a include but not limited to phones, video cameras, speakers, modems, printers and scanners equipped to wirelessly communicate in accordance with the Bluetooth protocol. Examples of devices 104b include clients and servers, as well as gateways, modems, hubs, routers, and switches equipped to wirelessly communicate in accordance with a selected variant of the IEEE 802.11 protocols or Home RF.
For ease of understanding, only two groups of devices 104a and 104b, communicating in accordance with the first and second wireless communication protocols are shown in FIG. 1. However, from the description to follow, it will be readily apparent to those skilled in the art, the present invention may be practiced with more than two transceivers (as long as the transceivers are likewise coordinated).

Referring now to FIGS. 3 and 4, wherein a block diagram and a state diagram illustrating wireless device 100 of FIG. 1 in further detail, in accordance with one embodiment, are shown. As illustrated, each controller manager 106a/106b of wireless device 100 is endowed with a state machine 300a/300b to complementarily assist the controller manager 106a/106b to control its transceiver 102a/102b in the above described coordinated manner. More specifically, each state machine 300a/300b, in addition to idle state 410, has four operating states 412–418 (TX, RX1, NOP, and RX2) to output a signal 304a/304b denoting a selected one of a transmit (TX) operation, a receive (RX) operation and no-op (NOP) for its controller manager 106a/106b.

Upon power-on or reset, each state machine 300a/300b, either transitions from idle state 410 to TX state 412 or NOP state 416, depending on the state of configuration (config) signal 302a/302b. One state machine, e.g., 300a, is configured to transition from idle state 410 to TX state 412, while the other state machine, e.g., 300b, is configured to transition from idle state 410 to RX state 414. Config signal 302a/302b may be set e.g. via a jumper or other equivalent means, as well as through software.

While in TX state 412, state machine 300a/300b remains in the state for duration ts1, outputting signal 304a/304b denoting TX operation for its controller manager 106a/106b. In one embodiment, where t1 and t3 may take on different values, one state machine, e.g., 300a, is configured with ts1 set to t1, while the other state machine, e.g., 300b, is configured with ts1 set to t3. ts1 may be selectively set in any one of a number of techniques known in the art. Upon expiration of ts2, state machine 300a/300b transitions from TX state 412 to RX1 state 414.

While in RX1 state 414, state machine 300a/300b remains in the state for duration ts2, outputting signal 304a/304b denoting RX operation for its controller manager 106a/106b. In one embodiment, where t2 and t4 may take on different values, one state machine, e.g., 300a, is configured with ts2 set to t2, while the other state machine, e.g., 300b, is configured with ts2 set to t4. ts2 may likewise be selectively set in any one of a number of techniques known in the art. Upon expiration of ts3, state machine 300a/300b transitions from RX1 state 414 to NOP state 416.

While in NOP state 416, state machine 300a/300b remains in the state for duration ts3, outputting signal 304a/304b denoting NOP for its controller manager 106a/106b. In one embodiment, where t1 and t3 may take on different values, one state machine, e.g., 300a, is configured with ts3 set to t3, while the other state machine, e.g., 300b, is configured with ts3 set to t1. ts3 may likewise be selectively set in any one of a number of techniques known in the art. Upon expiration of ts3, state machine 300a/300b transitions from NOP state 416 to RX2 state 418.

While in RX2 state 418, state machine 300a/300b remains in the state for duration ts4, outputting signal 304a/304b denoting RX operation for its controller manager 106a/106b. In one embodiment, where t2 and t4 may take on different values, one state machine, e.g., 300a, is configured with ts4 set to t4, while the other state machine, e.g., 300b, is configured with ts4 set to t2. ts4 may likewise be selectively set in any one of a number of techniques known in the art. Upon expiration of ts4, state machine 300a/300b transitions from RX2 state 418 to TX state 412.

From TX state 412, state machine 300a/300b continues operation as described earlier.

Referring now to FIGS. 5 and 6, wherein a block diagram and a state diagram illustrating wireless device 100 of FIG. 1 in further detail, in accordance with another embodiment, are shown. As illustrated, for this embodiment, instead of having each controller manager 106a/106b of wireless device 100 be endowed with a state machine to complementarily assist the controller manager 106a/106b to control its transceiver 102a/102b in the above described coordinated manner, wireless device 100 is endowed with a single state machine 500 to assist both controller managers 106a and 106b. Similarly, state machine 500, in addition to idle state 610, has four operating states 612–618 (S1–S4) to output a pair of signals 504a–504b denoting a selected combination of operations, TX with NOP, both RX, and NOP with TX for controller managers 106a and 106b.

Upon power-on or reset, state machine 500 transitions from idle state 610 to S1 state 612. While in S1 state 612, state machine 500 remains in the state for duration ts1, outputting signal 504a–504b denoting TX and NOP for controller managers 106a and 106b. ts1 is set to t1. Upon expiration of ts1, state machine 500 transitions from S1 state 612 to S2 state 614. While in S2 state 614, state machine 500 remains in the state for duration ts2, outputting signal 504a–504b denoting RX for both controller managers 106a and 106b. ts2 is set to t2. Upon expiration of ts2, state machine 500 transitions from S2 state 614 to S3 state 616.

While in S3 state 616, state machine 500 remains in the state for duration ts3, outputting signal 504a–504b denoting NOP and TX for controller managers 106a and 106b. ts3 is set to t3. Upon expiration of ts3, state machine 500 transitions from S3 state 616 to S4 state 618. While in S4 state 618, state machine 500 remains in the state for duration ts4, outputting signal 504a–504b denoting RX for both controller managers 106a and 106b. ts4 is set to t4. Upon expiration of ts4, state machine 500 transitions from S4 state 618 to S1 state 612.

From S1 state 612, state machine 500 continues operation as described earlier.

Referring now to FIG. 7, wherein a block diagram illustrating wireless device 100 of FIG. 1 in further detail, in accordance with yet another embodiment, is shown. As illustrated, for this embodiment, in addition to having wireless device 100 be endowed with a single state machine 700 to assist both controller managers 106a and 106b as described earlier (with signals 708a–708a denoting TX-NOP, RX-RX or NOP-TX), wireless device 100 is further endowed with register 702, time sharing manager 704, and workload monitor 706 operated cooperatively to couple each other and state machine 700 as shown. Register 702 stores t1–t4 for state machine 700. Time sharing manager 704 dynamically adjusts t1–t4 to enable state machine 700 to adaptively assist controller managers 106a and 106b in controlling transceivers 102a and 102b. For the illustrated embodiment, time sharing manager 704 dynamically adjusts t1–t4 based at least in part on transmit and receive workloads of networks 108a and 108b. Transmit and receive workloads are monitored by workload monitor 706 and provided to time sharing manager 704.

Register 702 may be constituted with any storage circuitry known in the art. Time sharing manager 704 and workload
monitor 706 may be implemented with any combinatorial logic or in software.

Referring now to FIGS. 8a–8b, wherein a period of operation for the wireless devices of FIG. 1 in accordance with each of two alternate embodiments are shown. In each of these two alternate embodiments, first protocol of wireless devices 104a of network 108a is assumed to be a frequency hopping protocol as shown, i.e. wireless devices 104a hop from frequency to frequency in accordance with a pseudo random pattern to transmit signals. For ease of understanding, second protocol of wireless devices 104b of network 108b is assumed to be a constant frequency protocol (although in alternate embodiments, it may also be a frequency hopping protocol). In any event, to illustrate the present invention, at least one of the frequencies of the first protocol is the same frequency of the second protocol. Thus, if some of devices 104a and 104b are located sufficiently close to each other, and when one of devices 104a selects the same frequency for transmission, interference (or collision) between these devices will occur, resulting in one or more transmission failures. For the illustrated example, frequency interference (or collision) is shown to occur at the 7th and 14th hop (f1 and f3). That is, in accordance with the pseudo random pattern, in each of these two hops, devices 104a transmit in the same frequency employed by devices 104b. An example of a frequency hopping protocol is the Bluetooth protocol, and an example of a protocol having an interfering frequency with Bluetooth is the 802.11 protocol. [Note that the example interference at the 7th and 14th hop is not intended to suggest that the interference occurs at every 7th hop. The interference pattern is dictated by the intersection of the pseudo random pattern followed by the frequency hopping devices 104a and the frequency employed by devices 104b.]

To further improve the operating efficiencies of both network, instead of just letting the interfering devices 104a and 104b resolve each of the frequency interference, after it occurred, through conventional collision detection, back off and retry approaches, wireless device 100 coordinates the operation of devices 104a and 104b to proactively reduce actual occurrence of interference. More specifically, for the illustrated embodiments, either devices 104a or devices 104b are selected to be the "dominant" devices. The non-selected devices are considered to be the dominated devices. The dominated devices are notified, from time to time, to suspend operation to pro-actively avoid interference with the dominant devices, allowing the dominant devices to continue to operate without interference. As result, the time consuming collision detection, back off and retries are substantially reduced, and experience has shown that the overall operating efficiencies of both networks improve, the dominated network as well as the dominant network.

FIG. 8a illustrates a period of operation when devices 104a, the frequency hopping devices, are selected to be the dominant devices, while FIG. 8b illustrates a period of operation when devices 104b are selected to be the dominant devices. That is, under FIG. 8a, devices 104b, upon informed, will temporarily suspend operation to proactively avoid interference, whereas under FIG. 8b, devices 104a, upon informed, will temporarily suspend operation to proactively avoid interference.

Under either one of these embodiments, wireless device 100 basically operates as earlier described. Except wireless device 100 assumes the additional responsibilities of determining the pseudo random frequency hopping pattern of devices 104a (in one embodiment, including the interfering frequency), selecting either devices 104a or 104b to be the dominated devices, predicting the occurrence of interference, and preemptively notifying the dominated devices to suspend operation to avoid interference (in one embodiment, conditionally suspending operation).

Referring now to FIGS. 9a–9b, wherein the architecture and operational flow of wireless device 100 having these added responsibilities are shown. As illustrated in FIG. 9a, wireless device 100 is basically the embodiment earlier described referencing FIG. 7, except wireless device 100 is further provided with network management application (or network manager) 904 to proactively managing network devices 104a and 104b to reduce actual occurrence of interference. Network manager 904 also subsumes the earlier described responsibilities of time sharing manager 704, i.e. monitoring the workloads of the two protocols, and adaptively setting the values of T1–T4 for time period T1–T4.

Operationally, as illustrated in FIG. 9b, upon initialization, network manager 904 monitors the operation of devices 104a and 104b for an observation period, and determines the pseudo random frequency hopping pattern followed by devices 104a (and in one embodiment, the interfering frequency with devices 104b). 912. This may be accomplished using any one of a number of techniques known in the art. Next, network manager 904 selects either devices 104a or devices 104b to be the dominant devices, 914. In one embodiment, network manager 904 makes the selection in accordance with configuration information programmed in configuration register 902. In alternate embodiments, other configuration registers, or other techniques known in the art, such as jumpers, may also be employed to assist network manager 904 in making the selection.

Then, on an on going basis, network manager 904, predicts when interference will occur, using the determined pseudo random pattern and interference frequency, 916. Whenever, an interference is to occur, network manager 904 preemptively notifies the dominated devices to suspend operation accordingly, thereby allowing the dominant devices to operate without interference, 918. [In one embodiment, if the dominated devices are devices 104a, the notification includes the interfering frequency, and the suspension is conditional, only if the predicted frequency is indeed the interfering frequency.] The process continues, as long as there are wireless devices of both types 104a and 104b operating.

In one embodiment, network manager 904 repeats the calibration periodically. In yet another embodiment, network manager 904 monitors actual interference between devices 104a and 104b, and tracks the mean time between interference. Network manager 904 repeats the calibration, whenever the tracked mean time between interference drops below certain given performance level.

Note that in embodiments where the number of devices 104a and 104b present in networks 108a and 108b are relatively small, including in particular, the simplest case where there is only one device 104a and one device 104b in networks 108a and 108b respectively, network manager 904 may make the selection of the dominated devices in a dynamic and individualized manner, when an interference is predicted to occur. That is, different device or devices 104a and 104b are dynamically and individually selected for different predictions of interference. Such dynamic, individualized manner of selection may also be made in view of the workloads of the two protocols.

As those skilled in the art would appreciate, the above described improved manner of operation (including the
embodiment, where suspension is to be conditionally made by devices 104a and 104b, as virtually all network devices are capable of temporarily suspending operation responsive to a request. As to the embodiment where suspension is to be conditionally made by devices 104a, the conditional performance may be effectuated through addition of simple frequency testing combinational logic. Additionally, in yet other embodiments, upon selecting the dominated devices at 914, wireless device 100 notifies devices 104a and 104b of their respective roles, i.e. whether they are the dominating devices or dominated devices. Further, at least the dominated devices are also provided with a collision map, for the dominated devices to self determine whether interference is to occur. In other words, operation 916 is distributed to the dominated devices, and operation 918 is eliminated.

In yet other embodiments where the wireless protocol is a frequency hopping protocol successively employing a number of frequencies in a pseudo random manner, independent of whether the interference determination is performed by wireless device 100 or the dominated devices, the determination of interference further includes prospectively anticipating whether the transmission of a long packet by a dominated device operating in accordance with such frequency hopping protocol will cause interference with the dominating devices. A long packet is a packet whose transmission spans multiple ones of the frequency hops. The dominated devices either self-determine or instructed by wireless device 100 (depending on implementations) to refrain from starting such transmission of a long packet unless interference will not occur.

Referring now to FIG. 10, wherein a period of operation for the wireless devices of FIG. 1 in accordance with another embodiment is shown. Again, first protocol of wireless devices 104a of network 108a is assumed to be a frequency hopping protocol, and second protocol of wireless devices 104b of network 108b is assumed to be a constant frequency protocol (although it may also be a frequency hopping protocol). Nevertheless, for illustrative purpose, it is suffice that at least one 4 of the frequencies of the first protocol of wireless devices 104a conflicts with the frequency of the second protocol of wireless devices 104b as shown, and earlier described. Thus, in like manner, if some of devices 104a and 104b are located sufficiently close to each other, and devices 104a select to transmit in the same frequency, interference (or collision) will occur, resulting in one or more transmission failures. To further improve the operating efficiencies of both network, instead of just letting the interfering devices 104a and 104b resolve each of the frequency interference, after it occurred, through conventional collision detection, back off and retry approaches, wireless device 100 coordinates the operation of devices 104a and 104b to proactively reduce actual occurrence of interference. More specifically, under this embodiment, devices 104a and 104b are correspondingly notified of the filtering to be employed to correspondingly cancel the respective interfering signals, and when to apply the filtering. As will be described in more detail below, in one embodiment, the filtering to be employed is a notch filter inversely formed in accordance with the other devices' signal. As a result, the time consuming collision detection, back off and retries are also substantially reduced, and experience has shown that the overall operating efficiencies of both networks also improve.

As illustrated in FIG. 10, at each predicted occurrence of interference, both devices 104a and 104b apply the corresponding required filtering to correspondingly cancel the respective interfering signals. As before, the basic operations of wireless device 100 remain substantially unchanged, except, wireless device 100 assumes the additional responsibilities of determining the pseudo random frequency hopping pattern of devices 104a, the interfering frequency, the corresponding filtering to be employed to cancel the respective interfering signals, and preemptively notifying devices 104a and 104b of the determined filtering as well as when to apply them.

Referring now to FIGS. 11a-11b, wherein the architecture and operational flow of wireless device 100 having these added responsibilities are shown. As illustrated in FIG. 1a, wireless device 100 is basically the embodiment earlier described referencing FIG. 9a. That is, wireless device 100 is also additionally provided with network manager 1104, except the additional responsibilities assumed by network manager 1104 to proactively reduce interference are slightly different.

As illustrated in FIG. 11b, upon initialization, network manager 1104 monitors the operation of devices 104a and 104b for an observation period, and determines the pseudo random frequency hopping pattern followed by devices 104a, and the interfering frequency with devices 104a, 1112. This again may be accomplished using any one of a number of techniques known in the art. Next, network manager 1104 determines the corresponding filtering to be employed by devices 104a and 104b to correspondingly cancel their respective interfering signals of “the other devices”, and provides the determined information to devices 104a and 104b, 1114. In one embodiment, as alluded to earlier, the corresponding filtering to be employed are notched filters inversely constructed in accordance with the other devices' signals (see FIG. 12). That is, devices 104a are to apply a notch filter, inversely formed in accordance with transmit signals of devices 104b, whereas, devices 104b are to apply a notch filter, inversely formed in accordance with transmit signals of devices 104a. [Notch filters in general are known in the art, and will not be further described.]

Then, on an ongoing basis, network manager 1104 predicts when interference will occur, using the determined pseudo random pattern and interference frequency, 1116. Whenever, an interference is to occur, network manager 1104 preemptively notifies devices 104a and 104b to correspondingly apply their corresponding filtering, thereby allowing both devices 104a and 104b to operate without interference, 1118. The process continues, as long as there are wireless devices of both types 104a and 104b operating. [Like-wise, the application of filtering by devices 104a may also be conditionally performed, only if the frequency is indeed the same as the interfering frequency.]

As before, in one embodiment, network manager 1104 repeats the calibration periodically. In yet another embodiment, network manager 1104 monitors actual interference between devices 104a and 104b, and tracks the mean time between interference. Network manager 1104 repeats the calibration, whenever the tracked mean time between interference drops below certain level.

As those skill in the art will appreciate, the immediately described improved manner of operation may also be practiced with minimal change to devices 104a and 104b, by equipping both types of network devices with the ability to responsively apply notch filtering. [Likewise, devices 104a may be additionally provided with simple combinatorial logic to effectuate the conditional application of notch filtering.]
Similar to the embodiments described with references to FIGS. 8a–8b and 9a–9b, in yet other embodiments, in addition to notifying the devices of the required filtering at 1114, wireless device 100 provides the devices with a collision map, such that the devices can self-determine whether interference is to occur, and the appropriate filtering to be applied. In other words, operation 1116 is distributed to the devices, and operation 1118 is eliminated.

 Skipping now to FIG. 14, wherein another overview of wireless device 100 of the present invention, along with devices 104a and 104b of wireless networks 108a and 108b are shown, in accordance with another embodiment. In this embodiment, the devices additionally operate in a complementary manner to proactively reduce interference among the devices. For illustrative purpose, wireless devices 104a are assumed to employ a frequency hopping protocol. Moreover, wireless devices 104a are subdivided into at least two subsets, with the devices of the two subsets employing successive frequencies in accordance with at least two corresponding pseudo random patterns. [In one embodiment, where the frequency hopping protocol is Bluetooth, each subset corresponds to a “piconet”. Note that even though for ease of understanding, only one device 104a is illustrated in each of the subset, the present invention may be practiced with each subset having one or more devices.]

In accordance with the present invention, to effectuate the desired proactive reduction of interference, the various subsets of devices 104a are operated in a synchronized manner (see FIG. 15). In one embodiment, the synchronization is effectuated by synchronizing transmit and receive operations of the various subsets to a reference signal. In one embodiment, the reference signal is provided by one of devices 104b. In other embodiments, the reference signal is provided by yet another device (not shown). Complementarily, devices 104b are also operated with transmit and receive operations aligned to the reference signal.

For this embodiment, in addition to having been incorporated with one or more of the novel features earlier described, wireless device 100 is further equipped to operate in a manner that is complementary to the synchronized operation of devices 104a and the aligned operation of devices 104b, to effectuate the desired reduction of interference among the devices. In particular, one or both controller managers 106a and 106b are equipped to enable the two controller managers 106a and 106b to operate with aligned control clocks for the two protocols.

More specifically, in one embodiment, controller manager or managers 106a and/or 106b are equipped such that when wireless device 100 joins wireless network 108b after having begun communication with devices 104a of at least one of the subsets, wireless device 100 would cause the two control clocks for the two protocols to be aligned incrementally. In one embodiment, the incremental alignment is effectuated in a dependent manner, depending on the amount of misalignment with respect to a transmission time slot. In one embodiment, the incremental alignment is effectuated by decrementing the start time of a transmission time slot by a predetermined amount for n successive transmission time slots if the amount of misalignment is less than half of the transmission time slot size, or by incrementing the start time of a transmission time slot by a predetermined amount for n successive transmission time slots if the amount of misalignment is less than half of the transmission time slot size.

In other words, if the transmission periods for the protocol employed by devices 104a are 0, B, 2B, . . . , kB (0<k<2^n), and the transmission time slots of the protocol employed by devices 104a start at d, d+S, d+2S, . . . , d+nS etc (0<d<S), the start time of a transmission time slot of the protocol of network 108b can be adjusted successively by t micro seconds for m or n successively transmission time slots, depending on whether d is less than or equal to S/2 or greater than S/2. In one embodiment, S is 625 micro seconds, and t is set to 8 micro seconds. For this embodiment, if d is less than or equal to S/2, m is set to the largest integer smaller than d/8, whereas if d is greater than S/2, n is set to the largest integer smaller than S–d/8.

In other embodiments, other criteria and/or parameters, even other incremental approaches may be employed instead. In one embodiment, the incremental alignment is repeated; however only after waiting for at least predetermined number of transmission time slots to “dampen oscillations”. In one embodiment, the predetermined number of transmission time slots waited is 10. In other embodiments, different waiting periods may be used instead.

Referring now to FIG. 13, wherein an overview of the present invention, in accordance with another embodiment, is shown. Similar to the embodiment of FIG. 1, wireless device 100 is communicatively coupled to devices 104a and devices 104b of wireless networks 108a and 108b respectively. Wireless device 100 performs transmits and receives of the two protocols, in a coordinated manner, to allow wireless device 100 to operate with devices 104a and devices 104b of wireless networks 108a and 108b in accordance with the respective protocols at the same time. However, unlike all the earlier described embodiments, wireless device 100 is provided with a single wireless transceiver 1302, which includes joint signal transmit/receive section 1303, and a number of transmit and receive signals up/down conversion sections 1305 sharing joint signal transmit/receive section 1303. Wireless device 100 further includes controller/signal processing (C/SP) section 1306 to process data for transmission by wireless transceiver 1302, to process signals received by wireless transceiver 1302, and to control the data/signal processing operations as well as the operation of wireless transceiver 1302. The constitution and operations of wireless device 100 is the subject of the second parent application Ser. No. 09/436,458, which is hereby fully incorporated by reference. Additionally, in some embodiments, wireless device 100 is endowed with a network manager equipped with the capabilities earlier described referencing FIGS. 8a–8b and 9a–9b, with or without the prospective interference anticipation for long packets. In other embodiments, wireless device 100 is endowed with a network manager equipped with the capabilities earlier described referencing FIGS. 110 and 11a–11b. In yet other embodiments, wireless device 100 is endowed with the capabilities earlier described referencing FIGS. 14 and 15. In one words, the capabilities and methods of operations described referencing FIGS. 8a–8b and 9a–9b, FIGS. 10 and 11a–11b, and FIGS. 14–15, may be practiced with the multiple protocol wireless apparatus of the first parent application Ser. No. 09/408,725, or the multiple protocol wireless apparatus of the second parent application.

Thus, a wireless device equipped to substantially operate currently with multiple wireless communication protocols, and various associated methods of operations, including proactive reduction of interference, have been described. While the present invention has been described in terms of the above illustrated embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described. The present invention can be practiced with modification and alteration within the spirit and
scope of the appended claims. The description is thus to be regarded as illustrative instead of restrictive on the present invention.

What is claimed is:

1. A collection of networked apparatuses comprising:
   a first plurality of apparatuses including first and second subsets wirelessly networked together, with each apparatus being equipped to communicate wirelessly in accordance with a first frequency hopping protocol, with the first and second subsets operating in accordance with a first and a second frequency hopping pattern based on a first and a second pseudo random pattern;

2. A second plurality of apparatuses wirelessly networked together, with each apparatus being equipped to communicate wirelessly in accordance with a second protocol;

wherein said first and second subsets of said first plurality of apparatuses are operationally synchronized and in wireless communication with a common wireless device, and said second plurality of apparatuses are operated in a manner complementary to said synchronized operation of said first and second subsets of said first plurality of apparatuses, to proactively reduce interference between said first and second plurality of apparatuses and wherein the common wireless device comprises a multi-protocol apparatus equipped with a transceiver to communicate wirelessly with said first and second plurality of apparatuses in accordance with said first and second protocols respectively, and in a manner that is complementary to said synchronized operation of said first and second subsets of said first plurality of apparatuses to proactively reduce interference with said first and second plurality of apparatuses;

wherein said first and second subsets are operationally synchronized to a reference signal, and said second plurality of apparatuses are operationally aligned to the same reference signal and said multi-protocol apparatus includes control logic to operate in a manner that is complementary to said synchronization as well as said alignment with respect to said reference signal, to effectuate said proactive reduction of interference among said apparatuses; and

wherein said control logic includes logic to effectuate said alignment to said reference signal incrementally, and in a selected one of at least a first and a second manner depending on an amount of misalignment.

2. The apparatuses of claim 1, wherein said logic decrements a transmission time slot starting time by a predetermined amount for m successive transmission time slots if the amount of misalignment is less than half of a transmission time slot size.

3. The apparatuses of claim 1, wherein said logic increments a transmission time slot starting time by a predetermined amount for n successive transmission time slots if the amount of misalignment is greater than half of a transmission time slot size.

4. An apparatus comprising:
   a plurality of wireless transceivers to transmit and receive signals in accordance with a first and a second protocol, to and from first and second network devices of a first and a second wireless network communicatively coupled to the apparatus, the first network devices comprising first and second subsets that transmit and receive in accordance with a first and a second frequency hopping pattern based on a first and a second pseudo random pattern in a synchronized manner wherein the first and second subsets are in wireless communication with a common wireless device, the first protocol being a frequency hopping protocol;
   at least one controller manager coupled to the wireless transceivers to control and coordinate operation of said wireless transceivers in a manner that complements said synchronized operation of said first and second subsets of said first network devices to reduce interference among said apparatus and said first and second network devices;

wherein the at least one controller manager includes logic to align transmit and receive operations of said wireless transceivers to a reference signal against which said first and second subsets of said first network devices synchronize operations; and

wherein said logic effectuates said alignment to said reference signal incrementally in a selected one of at least a first and a second manner depending on an amount of misalignment.

5. The apparatus of claim 4, wherein said logic decrements a transmission time slot starting time by a predetermined amount for m successive transmission time slots if the amount of misalignment is less than half of a transmission time slot size.

6. The apparatus of claim 4, wherein said logic increments a transmission time slot starting time by a predetermined amount for n successive transmission time slots if the amount of misalignment is greater than half of a transmission time slot size.

7. In an apparatus having a first and a second wireless transceiver, a method of operation comprising:
   controlling said first wireless transceiver to transmit and receive data to and from first and second subsets of first network devices of a first wireless network in accordance with a first protocol which is a frequency hopping protocol, and in a manner that is complementary to a synchronized manner of operation of the first and second subsets of said first network devices against which said first and second subsets of said first network devices synchronize operation, wherein said complementary manners of controlling comprise aligning transmit and receive operations of said first and second wireless transceivers to a reference signal against which said first and second subsets of said first network devices synchronize operations; and

wherein said alignment to said reference signal is effectuated incrementally in a selected one of at least a first and a second manner depending on an amount of misalignment.

8. The method of claim 7, wherein said incremental alignment comprises decrementing a transmission time slot starting time by a predetermined amount for m successive transmission time slots if the amount of misalignment is less than half of a transmission time slot size.

9. The method of claim 7, wherein said incremental alignment comprises incrementing a transmission time slot
starting time by a predetermined amount for n successive transmission time slots if the amount of misalignment is greater than half of a transmission time slot size.

10. A collection of networked apparatuses comprising:

a first plurality of apparatuses wirelessly networked together, with each apparatus being equipped to communicate wirelessly in accordance with a first frequency hopping protocol comprising a plurality of frequencies successively employed based on a pseudo random pattern;

a second plurality of apparatuses wirelessly networked together, with each apparatus being equipped to communicate wirelessly in accordance with a second protocol; and

a multi-protocol apparatus equipped to communicate wirelessly with said first and second plurality of apparatuses in accordance with said first and second protocols respectively, wherein the multi-protocol apparatus further at least facilities reduction of interference among said apparatuses, including at least facilitating prospective anticipation of whether interference will occur during transmission of a long packet by a selected one of said first plurality of apparatuses in accordance with said first protocol, said transmission of a long packet spanning multiple ones of said successive frequencies.

11. The collection of networked apparatuses of claim 10, wherein the multi-protocol apparatus includes a network manager equipped to determine the pseudo random frequency hopping pattern of said first network devices of said first wireless network.

12. The collection of networked apparatuses of claim 11, wherein the network manager is further equipped to predict when interference will occur between said first and second network devices of said first and second wireless networks, based on said determined pseudo random frequency hopping pattern.

13. The collection of networked apparatuses of claim 12, wherein the network manager is further equipped to provide said first/second network devices with collision maps.

14. The collection of networked apparatuses of claim 12, wherein the network manager is further equipped to inform said first/second network devices of anticipated interference.

15. An apparatus comprising:

at least one wireless transceiver to transmit and receive signals in accordance with a first and a second protocol and from first and second wireless devices of a first and a second wireless network respectively, said first protocol being a frequency hopping protocol comprising a plurality of frequencies successively employed in accordance with a pseudo random pattern; and

at least one controller manager coupled to the at least one wireless transceiver to control and coordinate performance of said transmits and receives, including at least facilitating of proactive reduction of interference among said apparatus and said network devices, by at least facilitating prospective anticipation of whether interference will occur during transmission of a long packet by a selected one of said first network devices in accordance with said first protocol, said transmission of a long packet spanning multiple ones of said successive frequencies.

16. The apparatus of claim 15, wherein the apparatus further includes a network manager equipped to determine the pseudo random frequency hopping pattern of said first network devices of said first wireless network.

17. The apparatus of claim 16, wherein the network manager includes logic to predict when interference will occur between said first and second network devices of said first and second wireless networks, based on said determined pseudo random frequency hopping pattern.

18. The apparatus of claim 17, wherein the network manager is further equipped to provide said first/second network devices with collision maps.

19. The apparatus of claim 17, wherein the network manager is further equipped to inform said first/second network devices of anticipated interference.

20. The apparatus of claim 15, wherein the first protocol is a version of Bluetooth, and the second protocol is a protocol selected from a group consisting of a version of 802.11 frequency hopping, 802.11 direct sequence, 802.11a, 802.11b, and Home RF.

21. The apparatus of claim 15, wherein the apparatus is a computer having a form factor selected from a group consisting of a desktop type, a notebook type, and a palm sized type.

22. In an apparatus having at least one wireless transceiver and at least one controller manager; a method of operation comprising:

controlling said at least one wireless transceiver to transmit and receive signals in accordance with a first and a second protocol to and from first and second wireless devices of a first and a second wireless network respectively, said first protocol being a frequency hopping protocol comprising a plurality of frequencies successively employed in accordance with a pseudo random pattern; and

at least facilitating prospective reduction of interference among said apparatus and said network devices, by at least facilitating prospective anticipation of whether interference will occur during transmission of a long packet by a selected one of said first network devices in accordance with said first protocol, said transmission of a long packet spanning multiple ones of said successive frequencies.

23. The method of claim 22, wherein said at least facilitating includes determining the pseudorandom frequency hopping pattern of said first network devices of said first wireless network.

24. The method of claim 23, wherein said at least facilitating further includes predicting when interference will occur between said first and second network devices of said first and second wireless networks, based on said determined pseudorandom frequency hopping pattern.

25. The method of claim 24, wherein said at least facilitating further comprises providing said first/second network devices with collision maps.

26. The method of claim 24, wherein said at least facilitating further comprises informing said first/second network devices of anticipated interference.