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(54) **EMULATION OF N-BITS UNIFORM QUANTIZER FROM MULTIPLE INCOHERENT AND NOISY ONE-BIT MEASUREMENTS**

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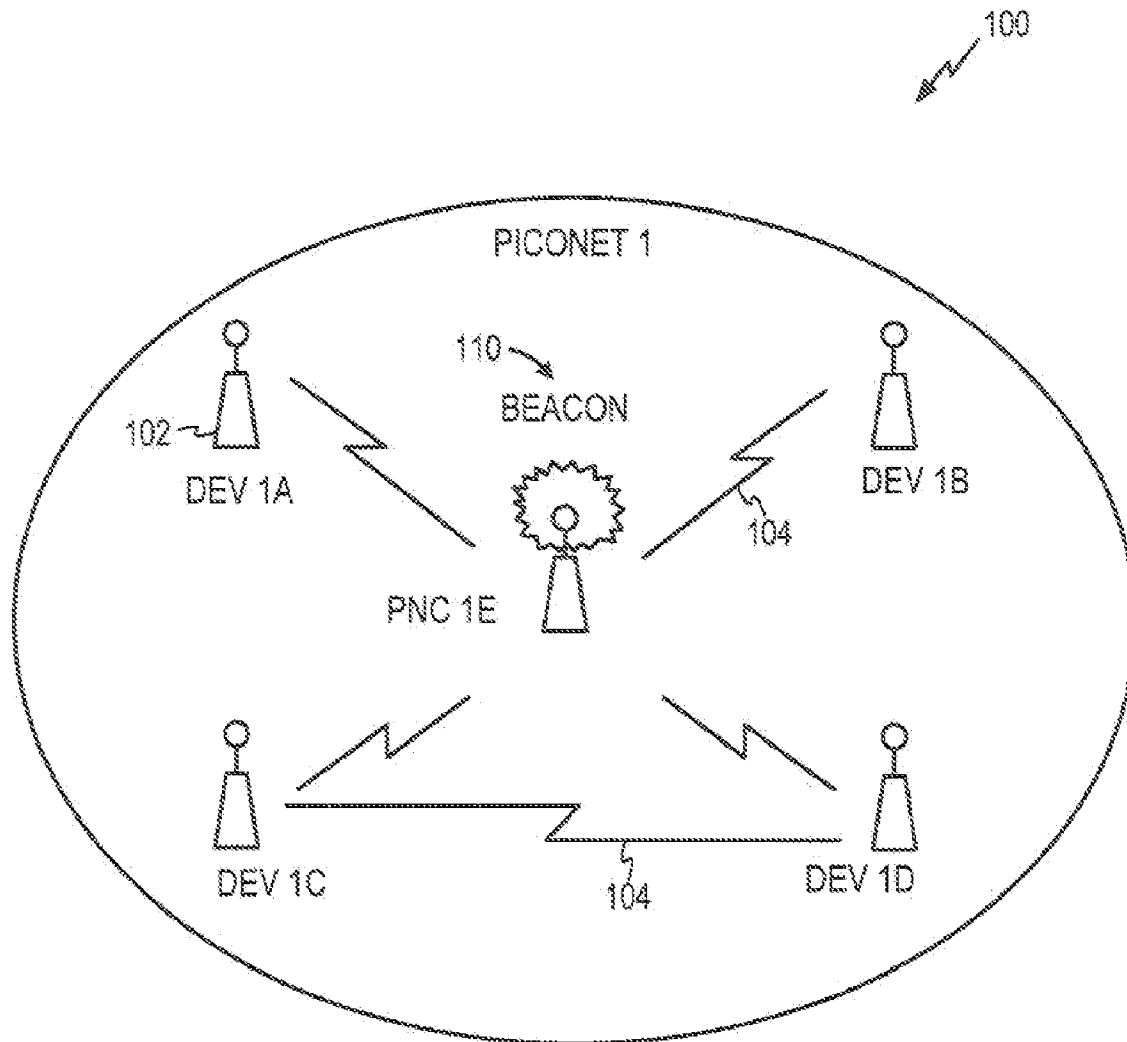
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(57) **ABSTRACT**

(21) Appl. No.: **12/577,905**

Certain aspects of the present disclosure relate to a method for emulating N-bits uniform quantization of a received pulse signal by using one-bit signal measurements.



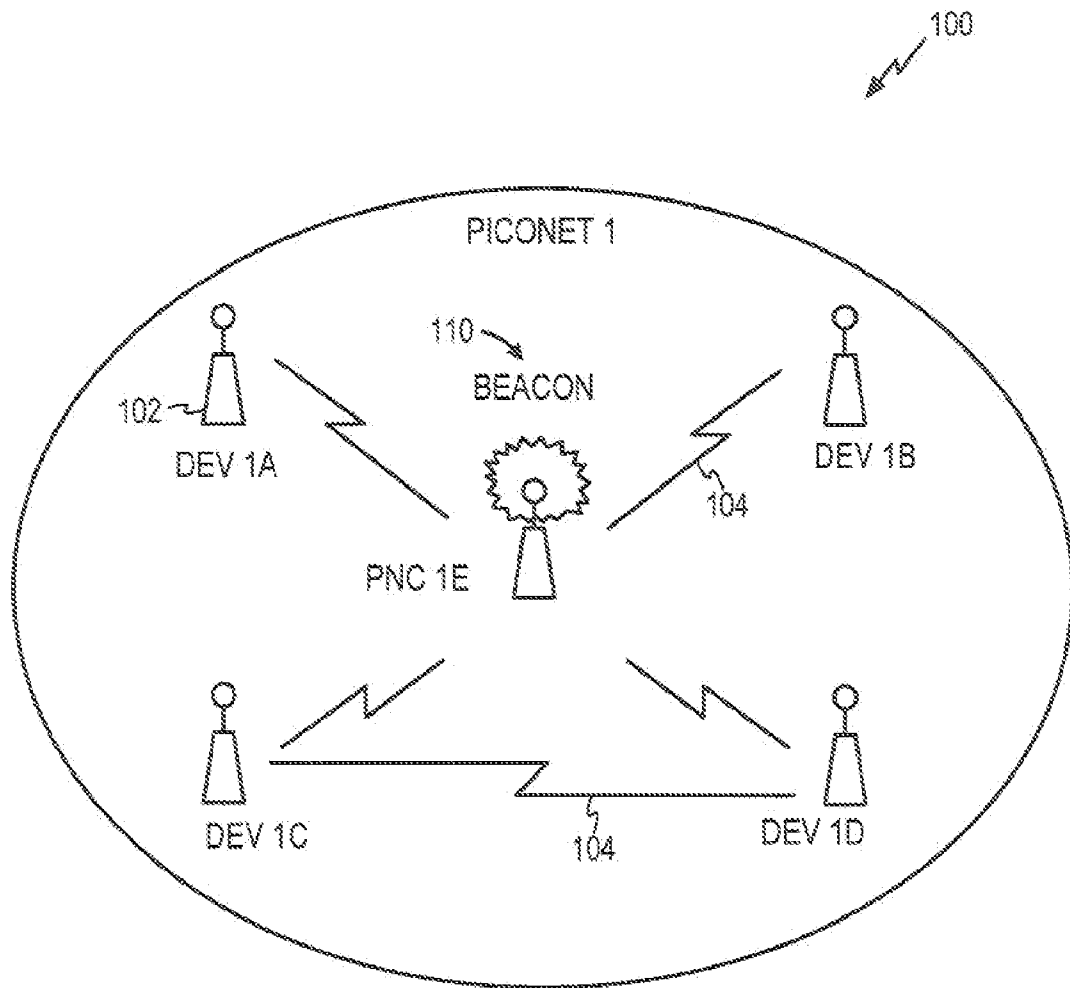


FIG. 1

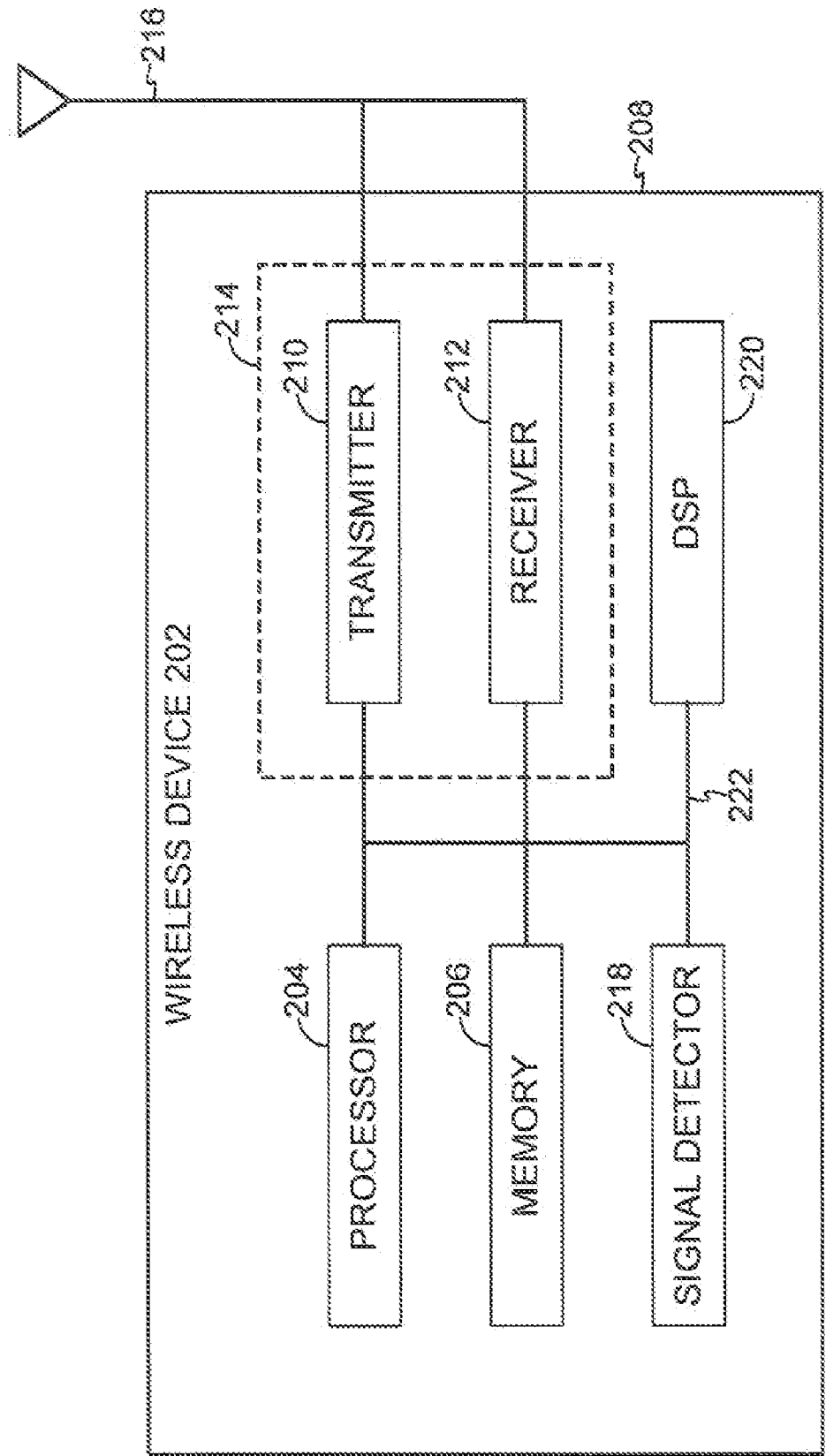


FIG. 2

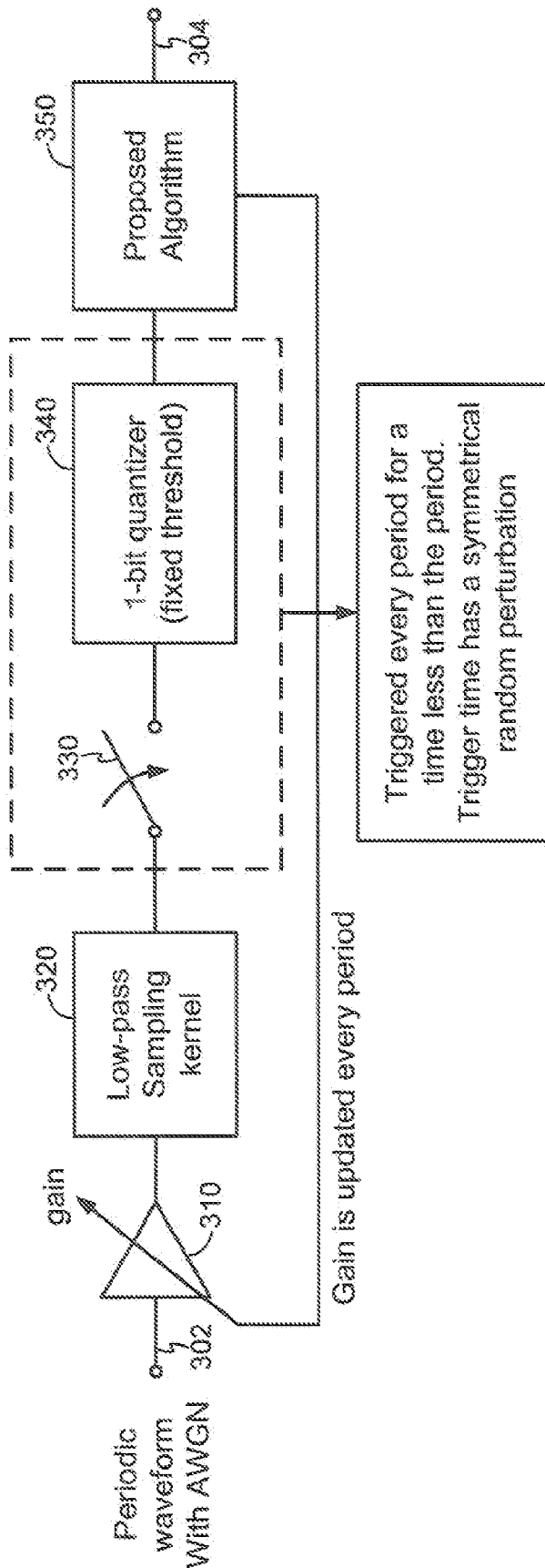


FIG. 3

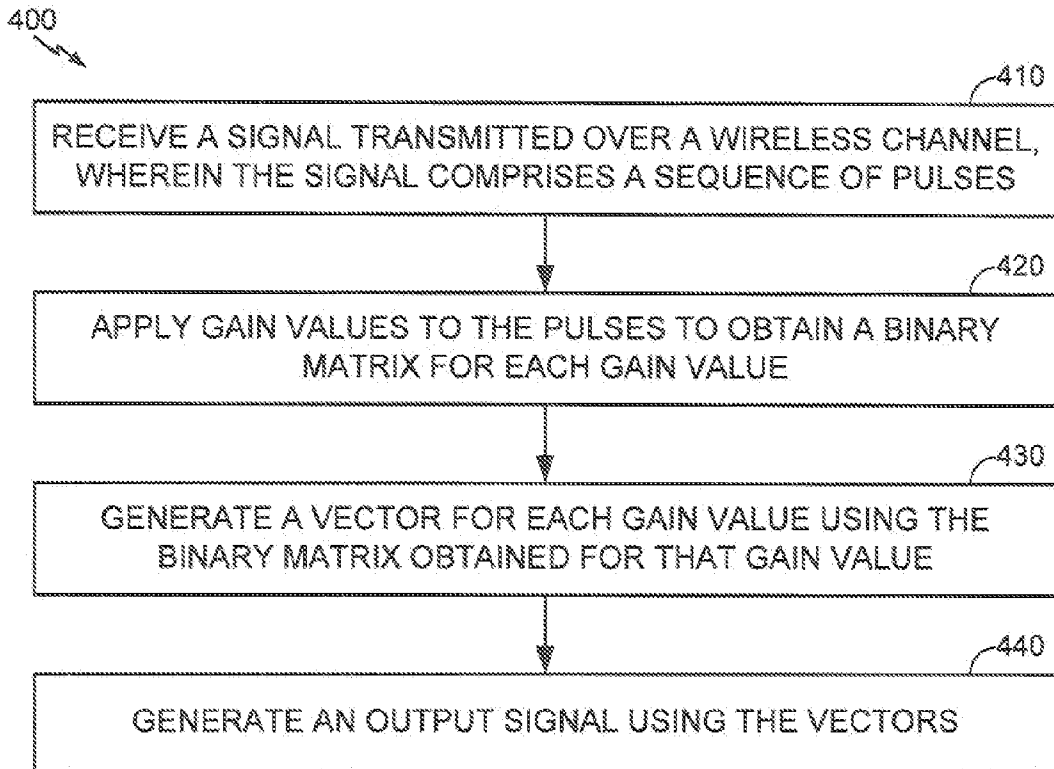


FIG. 4

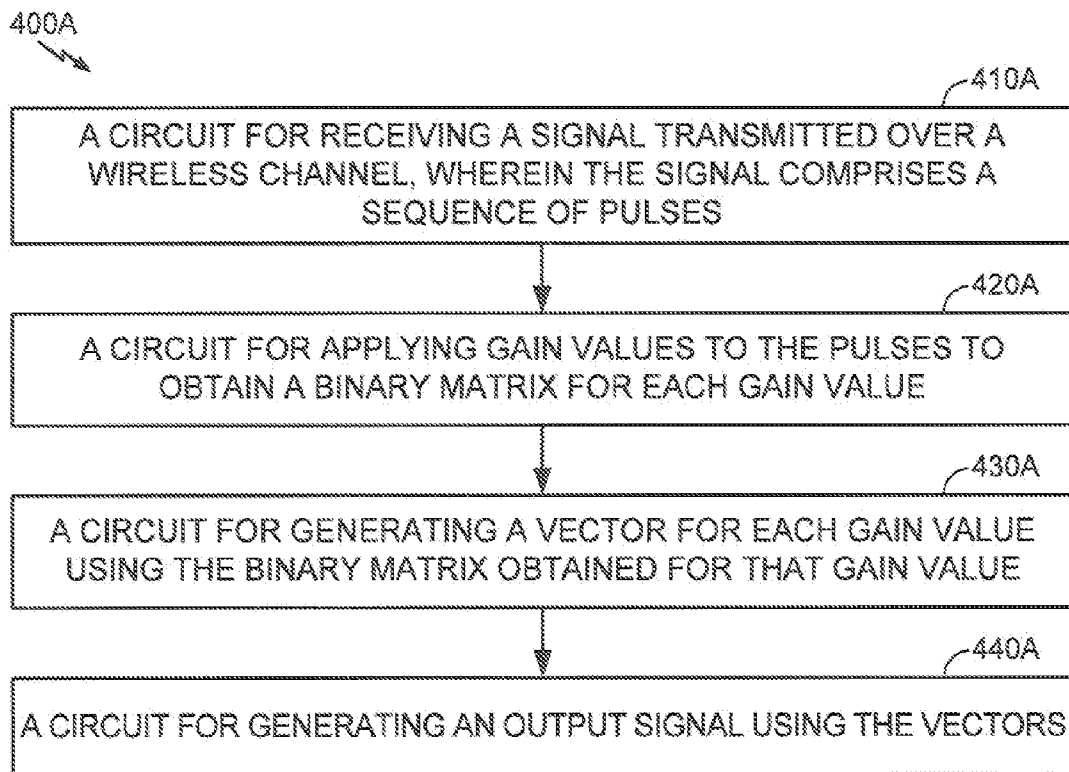


FIG. 4A

**EMULATION OF N-BITS UNIFORM QUANTIZER FROM MULTIPLE INCOHERENT AND NOISY ONE-BIT MEASUREMENTS**

CLAIM OF PRIORITY UNDER 35 U.S.C. §119

**[0001]** The present application for patent claims benefit of Provisional Application Ser. Nos. 61/161,348 filed Mar. 18, 2009 (Our Docket No.: 091638P1), 61/161,656 filed Mar. 19, 2009 (Our Docket No.: 091638P2), 61/224,808 filed Jul. 10, 2009 (Our Docket No.: 091638P3), and 61/247,128 filed Sep. 30, 2009 (Our Docket No.: 091628P1), and assigned to the assignee hereof and hereby expressly incorporated by reference herein.

**BACKGROUND**

**[0002]** 1. Field

**[0003]** Certain aspects of the present disclosure generally relate to a wireless communication and, more particularly, to quantizing a received pulse signal with a high resolution by employing one-bit quantizer.

**[0004]** 2. Background

**[0005]** Ultra-Wideband (UWB) communications are radio communications that use a frequency bandwidth larger than 500 MHz. In comparison to narrow-band communications which rely on modulation of a carrier frequency, the large bandwidth of UWB communications allows sending signals with features well-localized in time. If a signal is more localized in time, then it is more spread in frequency. This allows communications based on pulses, while information can be encoded in a distance between pulses (i.e., a Pulse Position Modulation: PPM), in a pulse amplitude (i.e., a Pulse Amplitude Modulation: PAM) or in a pulse width (i.e., Pulse Width Modulation: PWM). One of the key advantages of pulse-based communication is ability to precisely localize time of arrival of the information (i.e., arrival of the pulse).

**[0006]** It is desirable that quantization of an analog received UWB pulse signal is implemented with a low cost and low power dissipation. In order to achieve these requirements, a number of quantization bits needs to be small. However, the small number of quantization bits can introduce distortion in the digitized UWB pulse signal, which negatively affects the reconstruction accuracy.

**[0007]** A method is proposed in the present disclosure to quantize the periodic pulse signal at the UWB receiver by using a limited number of quantization bits, while information of the received pulse signal is preserved for accurate signal reconstruction.

**SUMMARY**

**[0008]** Certain aspects provide a method for wireless communications. The method generally includes receiving a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses, applying gain values to the pulses to obtain a binary matrix for each gain value, generating a probability vector for each gain value using the binary matrix obtained for that gain value, and generating an output signal using the probability vectors.

**[0009]** Certain aspects provide an apparatus for wireless communications. The apparatus generally includes a receiver configured to receive a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses, an amplifier configured to apply gain values to the pulses to

obtain a binary matrix for each gain value, a first generator configured to generate a probability vector for each gain value using the binary matrix obtained for that gain value, and a second generator configured to generate an output signal using the probability vectors.

**[0010]** Certain aspects provide an apparatus for wireless communications. The apparatus generally includes means for receiving a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses, means for applying gain values to the pulses to obtain a binary matrix for each gain value, means for generating a probability vector for each gain value using the binary matrix obtained for that gain value, and means for generating an output signal using the probability vectors.

**[0011]** Certain aspects provide a computer-program product for wireless communications. The computer-program product includes a computer-readable medium comprising instructions executable to receive a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses, apply gain values to the pulses to obtain a binary matrix for each gain value, generate a probability vector for each gain value using the binary matrix obtained for that gain value, and generate an output signal using the probability vectors.

**[0012]** Certain aspects provide a headset. The headset generally includes a receiver configured to receive a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses, an amplifier configured to apply gain values to the pulses to obtain a binary matrix for each gain value, a first generator configured to generate a probability vector for each gain value using the binary matrix obtained for that gain value, a second generator configured to generate an output signal using the probability vectors, and a transducer configured to provide an audio output based on the generated output signal.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**[0013]** So that the manner in which the above-recited features of the present disclosure can be understood in detail, a more particular description, briefly summarized above, may be had by reference to aspects, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only certain typical aspects of this disclosure and are therefore not to be considered limiting of its scope, for the description may admit to other equally effective aspects.

**[0014]** FIG. 1 illustrates an example wireless communication system in accordance with certain aspects of the present disclosure.

**[0015]** FIG. 2 illustrates various components that may be utilized in a wireless device in accordance with certain aspects of the present disclosure.

**[0016]** FIG. 3 illustrates a receiver setup for sequential N-bit quantization from multiple incoherent binary slices obtained using one-bit quantizer in accordance with certain aspects of the present disclosure.

**[0017]** FIG. 4 illustrates example operations for sequential N-bit quantization from multiple incoherent binary slices in accordance with certain aspects of the present disclosure.

**[0018]** FIG. 4A illustrates example components capable of performing the operations illustrated in FIG. 4.

## DETAILED DESCRIPTION

**[0019]** Various aspects of the disclosure are described more fully hereinafter with reference to the accompanying drawings. This disclosure may, however, be embodied in many different forms and should not be construed as limited to any specific structure or function presented throughout this disclosure. Rather, these aspects are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art. Based on the teachings herein, one skilled in the art should appreciate that the scope of the disclosure is intended to cover any aspect of the disclosure disclosed herein, whether implemented independently of or combined with any other aspect of the disclosure. For example, an apparatus may be implemented or a method may be practiced using any number of the aspects set forth herein. In addition, the scope of the disclosure is intended to cover such an apparatus or method which is practiced using other structure, functionality, or structure and functionality in addition to or other than the various aspects of the disclosure set forth herein. It should be understood that any aspect of the disclosure disclosed herein may be embodied by one or more elements of a claim.

**[0020]** The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any aspect described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other aspects.

**[0021]** Although particular aspects are described herein, many variations and permutations of these aspects fall within the scope of the disclosure. Although some benefits and advantages of the preferred aspects are mentioned, the scope of the disclosure is not intended to be limited to particular benefits, uses, or objectives. Rather, aspects of the disclosure are intended to be broadly applicable to different wireless technologies, system configurations, networks, and transmission protocols, some of which are illustrated by way of example in the figures and in the following description of the preferred aspects. The detailed description and drawings are merely illustrative of the disclosure rather than limiting, the scope of the disclosure being defined by the appended claims and equivalents thereof.

## An Example Wireless Communication System

**[0022]** The techniques described herein may be used for various broadband wireless communication systems, including communication systems that are based on a single carrier transmission. Aspects disclosed herein may be advantageous to systems employing Ultra-Wideband (UWB) signals including millimeter-wave signals. However, the present disclosure is not intended to be limited to such systems, as other coded signals may benefit from similar advantages.

**[0023]** The teachings herein may be incorporated into (e.g., implemented within or performed by) a variety of wired or wireless apparatuses (e.g., nodes). In some aspects, a node implemented in accordance with the teachings herein may comprise an access point or an access terminal.

**[0024]** An access terminal (“AT”) may comprise, be implemented as, or known as an access terminal, a subscriber station, a subscriber unit, a mobile station, a remote station, a remote terminal, a user terminal, a user agent, a user device, user equipment, or some other terminology. In some implementations an access terminal may comprise a cellular telephone, a cordless telephone, a Session Initiation Protocol (“SIP”) phone, a wireless local loop (“WLL”) station, a per-

sonal digital assistant (“PDA”), a handheld device having wireless connection capability, or some other suitable processing device connected to a wireless modem. Accordingly, one or more aspects taught herein may be incorporated into a phone (e.g., a cellular phone or smart phone), a computer (e.g., a laptop), a portable communication device, a portable computing device (e.g., a personal data assistant), an entertainment device (e.g., a music or video device, or a satellite radio), a global positioning system device, a headset, a sensor or any other suitable device that is configured to communicate via a wireless or wired medium. In some aspects the node is a wireless node. Such wireless node may provide, for example, connectivity for or to a network (e.g., a wide area network such as the Internet or a cellular network) via a wired or wireless communication link.

**[0025]** FIG. 1 illustrates an example of a wireless communication system **100** (i.e., a Piconet **1**) in which aspects of the present disclosure may be employed. As illustrated, Piconet **1** may include a number of wireless devices **102** or “terminals” **1A-1E** that can communicate with one another using relatively short-range wireless links **104**. In the illustrated example, terminal **1E** acts as a PNC for Piconet **1**. Although illustrated with five devices, it should be appreciated that any number of devices (i.e., two or more) may form a wireless personal area network.

**[0026]** Each of the terminals **102** in the Piconet **1** may include, among other things, a wireless transceiver to support wireless communication and controller functionality to manage communication with the network. The controller functionality may be implemented within one or more digital processing devices. The wireless transceiver may be coupled to one or more antennas to facilitate the transmission of signals into and the reception of signals from a wireless channel. Any type of antennas may be used including, for example, dipoles, patches, helical antennas, antenna arrays, and/or others.

**[0027]** The devices in the Piconet **1** may include any of a wide variety of different device types including, for example, laptop, desktop, palmtop, or tablet computers having wireless networking functionality, computer peripherals having wireless networking capability, personal digital assistants (PDAs) having wireless networking capability, cellular telephones and other handheld wireless communicators, pagers, wireless network interface modules (e.g., wireless network interface cards, etc.) incorporated into larger systems, multimedia devices having wireless networking capability, audio/visual devices having wireless networking capability, home appliances having wireless networking capability, jewelry or other wearable items having wireless networking capability, wireless universal serial bus (USB) devices, wireless digital imaging devices (e.g., digital cameras, camcorders, etc.), wireless printers, wireless home entertainment systems (e.g., DVD/CD players, televisions, MP3 players, audio devices, etc.), and/or others. In one configuration, for example, a wireless personal area network may include a user’s laptop computer that is wirelessly communicating with the user’s personal digital assistant (PDA) and the user’s printer in a short-range network. In another possible configuration, a wireless personal area network may be formed between various audio/visual devices in, for example, a user’s living room. In yet another configuration, a user’s laptop computer may communicate with terminals associated with other users in a vicinity of the user. Many other scenarios are also possible.

**[0028]** Standards have been developed, and are currently in development, to provide a framework to support development of interoperable products that are capable of operating as part of a wireless personal area network (e.g., the Bluetooth standard (Specification of the Bluetooth System, Version 3.0, Bluetooth SIG, Inc., April 2009), the IEEE 802.15 standards, etc.). The IEEE 802.15.3c standard, for example, is a high data rate wireless personal area network standard. In accordance with the IEEE 802.15.3c standard, one of the terminals within a piconet is selected as a Piconet Coordinator (PNC) to coordinate the operation of the network. For example, with reference to FIG. 1, the device PNC 1E represents a PNC for the Piconet 1 in an IEEE 802.15.3c implementation.

**[0029]** As illustrated, PNC 1E may transmit a beacon signal 110 (or simply “beacon”) to other devices of Piconet 1, which may help the other terminals within Piconet 1 synchronize their timing with PNC 1E. Thus, the beacon, typically sent at the beginning of every superframe, contains information that may be used to time-synchronize the terminals in the piconet. Each terminal in the piconet, including the PNC, may reset its superframe clock to zero at the beginning of the beacon preamble. If a terminal does not hear a beacon, it may reset its superframe clock to zero at the instant where it expected to hear the beginning of the beacon preamble (e.g., based on previous superframe timing).

**[0030]** In addition, terminals 102 can be communicating with one another in a peer-to-peer configuration. For example, the device DEV 1C may be in communication with the device DEV 1D using the link 104. In peer-to-peer ad hoc networks, devices (nodes) within range of each other, such as the devices DEV 1C and DEV 1D in the network 100, can communicate directly with each other without an access point, such as the PNC 1E, and/or a wired infrastructure to relay their communication. Additionally, peer devices or nodes can relay traffic. The devices 102 within the network 100 communicating in a peer-to-peer manner can function similar to base stations and relay traffic or communications to other devices, functioning similar to base stations, until the traffic reaches its ultimate destination. The devices can also transmit control channels, which carry information that can be utilized to manage the data transmission between peer nodes.

**[0031]** The communication network 100 can include any number of devices or nodes that are in wireless (or wired) communication. Each node can be within range of one or more other nodes and can communicate with the other nodes or through utilization of the other nodes, such as in a multi-hop topography (e.g., communications can hop from node to node until reaching a final destination). For example, a sender node may wish to communicate with a receiver node. To enable packet transfer between sender node and receiver node, one or more intermediate nodes can be utilized. It should be understood that any node can be a sender node and/or a receiver node and can perform functions of either sending and/or receiving information at substantially the same time (e.g., can broadcast or communicate information at about the same time as receiving information) or at different times.

**[0032]** FIG. 2 illustrates various components that may be utilized in a wireless device 202 that may be employed within the wireless communication system 100. The wireless device 202 is an example of a device that may be configured to

implement the various methods described herein. The wireless device 202 may be the PNC 1E or a terminal 102 in the Piconet 1.

**[0033]** The wireless device 202 may include a processor 204 which controls operation of the wireless device 202. The processor 204 may also be referred to as a central processing unit (CPU). Memory 206, which may include both read-only memory (ROM) and random access memory (RAM), provides instructions and data to the processor 204. A portion of the memory 206 may also include non-volatile random access memory (NVRAM). The processor 204 typically performs logical and arithmetic operations based on program instructions stored within the memory 206. The instructions in the memory 206 may be executable to implement the methods described herein.

**[0034]** The wireless device 202 may also include a housing 208 that may include a transmitter 210 and a receiver 212 to allow transmission and reception of data between the wireless device 202 and a remote location. The transmitter 210 and receiver 212 may be combined into a transceiver 214. An antenna 216 may be attached to the housing 208 and electrically coupled to the transceiver 214. The wireless device 202 may also include (not shown) multiple transmitters, multiple receivers, multiple transceivers, and/or multiple antennas.

**[0035]** The wireless device 202 may also include a signal detector 218 that may be used in an effort to detect and quantify the level of signals received by the transceiver 214. The signal detector 218 may detect such signals as total energy, energy per subcarrier per symbol, power spectral density and other signals. The wireless device 202 may also include a digital signal processor (DSP) 220 for use in processing signals.

**[0036]** The various components of the wireless device 202 may be coupled together by a bus system 222, which may include a power bus, a control signal bus, and a status signal bus in addition to a data bus.

**[0037]** Ultra-Wideband (UWB) communications performed by the wireless system 100 comprise radio communications that use a frequency bandwidth larger than 500 MHz. In comparison to narrow-band communications which rely on modulation of a carrier frequency, the large bandwidth of UWB communications allows sending signals with features well-localized in time. If a signal is more localized in time, then it is more spread in frequency. This allows communications based on pulses, while information can be encoded in a distance between pulses (i.e., a Pulse Position Modulation: PPM), in a pulse amplitude (i.e., a Pulse Amplitude Modulation: PAM) or in a pulse width (i.e., Pulse Width Modulation: PWM). One of the key advantages of pulse-based communication is ability to precisely localize time of arrival of the information (i.e., arrival of the pulse).

**[0038]** Finite Rate of Innovation (FRI) is a parametric processing approach that may be applied on signals received by a typical Ultra-Wideband (UWB) device, such as the device 202. The FRI processing may require a quantized (digital) input signal based on the periodic-sinc function. Because of that, the received signal at the UWB device may need to be appropriately processed and adjusted before being input into the FRI processing module. Certain aspects of the present disclosure support low-cost and low-power quantization of the received signal based on a sequential one-bit quantization.

#### Sequential Quantization from Multiple Incoherent Binary Slices

**[0039]** Certain aspects of the present disclosure support a method for recovering a waveform corrupted by a noise with



unknown power from binary slices acquired at each signal period using a one-bit quantizer. The same waveform may be repeated from one transmission frame to another. The receiver setup illustrated in FIG. 3 may comprise a variable gain amplifier 310 with gain  $g$  followed by a low-pass sampling kernel 320. The low-pass sampling kernel 320 may be followed by a sampler with a trigger mechanism 330. The sampler 330 may be followed by the one-bit quantizer 340 with a fixed threshold. The sampler 330 may be triggered every signal period for a time period with duration shorter than the signal period. The trigger time period may have a symmetrical random perturbation.

**[0040]** The input signal 302 may be a pulse signal corrupted by an additive white Gaussian noise (AWGN) with mean  $\mu$  and standard deviation  $\sigma$ . The signal-to-noise ratio (SNR) represents the ratio between energy of the received signal and the energy of noise. The quantized output signal 304 may be generated based on the proposed algorithm 350 for each period of the signal, and it may be represented by a sequence of  $M$  binary samples covering a portion of the signal period. The covered portion may vary from one period to another period according to a symmetric and possibly non-centered distribution  $D$ . The mean of this distribution represents a drift  $\Delta$  and the centered distribution  $D-\Delta$  represents a jitter. A total number of available periods can be denoted by  $P'$ , while a remaining number of periods after a sweep procedure and a dichotomic search is  $P$ , where  $P < P'$ .

**[0041]** Certain aspects of the present disclosure support determining a smallest gain value  $g_{min}$  on a peak of the received signal. A proposed technique for determining this value is described below.

**[0042]** Intensity of the received signal may be found by sweeping exponentially the gain  $g$  from one period to another until an all-zero output is obtained. It can be assumed that  $\{g_0, \dots, g_S\}$  is the sequence of gains covered during the sweep, such that the gain  $g_0$  may represent a highest overall gain value (i.e.,  $g_{max}=g_0$ ) causing the threshold of the one-bit quantizer 340 referred to the input signal 302 to be within a noise level (typically within  $\mu \pm 2\sigma$ ). The gain may be then exponentially decreased having values  $g_1, g_2, \dots, g_S$  until the all-zero output is obtained at the  $S^{th}$  step of the sweep procedure. The last interval  $[g_{S-1}, g_S]$  may then comprise a smallest gain value  $g_{min}$ .

**[0043]** The interval  $[g_{S-1}, g_S]$  may be refined by employing the dichotomic search until desired quantization accuracy is obtained. The interval may be cut in half (or as close to half as possible) at each search step, and the minimum gain (i.e., the largest threshold) that yields the all-zero output vector during the dichotomic search may correspond to  $g_{min}$ .

**[0044]** A largest gain value  $g_{max}$  may be determined based on the previously determined largest gain value  $g_0$ , the previously determined smallest gain value  $g_{min}$ , and a pre-defined constant value. In one aspect of the present disclosure,  $g_{max}$  may be set equal to  $g_0$ . In another aspect of the present disclosure,  $g_{max}$  may be set as the product of  $g_{min}$  and the pre-defined constant value. Several constant values may be multiplied to the smallest gain value  $g_{min}$  in order to obtain several gain values within the range of gain values  $[g_{max}, g_{min}]$ .

**[0045]** A number  $n_g$  of gain values to be used may be determined by the ratio  $g_{max}/g_{min}$ , which depends solely on a signal-to-noise ratio (SNR) at the receiver (i.e., on a received signal power) and on a variance  $\sigma_D^2$  of the distribution  $D$ , assuming that an ambient noise is constant (i.e., a noise variance is fixed). The number of gain values  $n_g$  may increase

with the ratio  $g_{max}/g_{min}$  and may decrease with  $\sigma_D^2$ . The vector of gains used for quantization (after the sweep and dichotomic search) may be obtained as:

$$\gamma = [\gamma_1, \gamma_2, \dots, \gamma_{n_g}] = [g_{max}, g_{max}/2, \dots, g_{max}/n_g]. \quad (1)$$

$[P/n_g]$  periods may be acquired with each gain from  $\gamma$ . Acquisition with different gains may be interleaved in time. The acquisition results may be represented with binary matrices  $B_i$  of size  $[P/n_g] \times M$  associated with each gain  $\gamma_i, i=1, \dots, n_g$ .

**[0046]** A  $1 \times M$  vector  $b_i$  may be obtained from each of the matrices  $B_i$  by taking the average of each column. Each entry of the vector  $b_i$  can be therefore interpreted as a “rate of ones” per column of the matrix  $B_i$ . The quantized output vector  $y_Q$  may be obtained as:

$$y_Q = \sum_{i=1}^{n_g} \left[ v_i \prod_{j=1}^i b_j \prod_{k=i+1}^{n_g} (1 - b_k) \right], \quad (2)$$

such that

$$v_i = \frac{i}{n_g}.$$

Certain aspects of the present disclosure support obtaining the quantized output signal by linearly combining all or some of the vectors  $b, i=1, \dots, n_g$ .

**[0047]** The output signal may be further de-convoluted by the jitter distribution  $D-\Delta$  to obtain the originally transmitted pulse-shape signal. The deconvolution may be performed, for example, by employing the Wiener deconvolution filter.

**[0048]** Equation (2) provides the output quantization value generated if slices obtained with different gains are randomly paired, while only valid slices are preserved. As an exemplary case, three different gain levels  $g_1, g_2, g_3$  can be considered, as well as generation of the arbitrary  $i^{th}$  entry of the quantized output  $y_Q$  given by equation (2). The columns  $B_1[:,1], B_2[:,1], B_3[:,1]$  of the corresponding binary matrices can be utilized, while  $g_1 > g_2 > g_3$ . If one entry is randomly drawn from each of these three columns, then the following vectors of slices may be obtained:  $[000], [100], [110]$  or  $[111]$  representing valid combinations of slices since  $g_1 > g_2 > g_3$ . Invalid results, such as  $[010]$  or  $[101]$  may be discarded. The value  $i/n_g$  may be assigned to each valid combination of slices, i.e.  $v_i = i/n_g$ , where  $i=1, \dots, n_g$ , as defined in equation (2).

**[0049]** If this experiment is repeated a large number of times and each of the valid vectors is interpreted as a word from the 2-bits uniform quantizer,  $00 \rightarrow 0, 01 \rightarrow 1/3, 10 \rightarrow 2/3, 11 \rightarrow 1$ , then the average quantized value may probabilistically tend to equation (2). In this case, the following may be satisfied:

$$\lim_{T \rightarrow \infty} Pr \left[ \left| \frac{1}{T} \cdot \sum_{t=1}^T v(t) \right| - V_1 \right| > \epsilon \right] = 0, \forall \epsilon > 0, \quad (3)$$

where  $T$  is a number of trials (experiments),  $v(t)$  represents  $v_i$  value obtained by a trial number  $t$ , and  $V_1$  is the value obtained from equation (2).

**[0050]** FIG. 4 illustrates example operations 400 for sequential N-bit quantization from multiple incoherent binary slices obtained using one-bit quantizer in accordance with certain aspects of the present disclosure. At 410, a signal transmitted over a wireless channel may be received, wherein the signal comprises a sequence of pulses. At 420, gain values may be applied to the pulses to obtain a binary matrix for each gain value. At 430, a probability vector for each gain value may be generated using the binary matrix obtained for that gain value. At 440, an output signal may be generated using the previously generated probability vectors. For example, the quantized output signal may be generated as defined by equation (1).

**[0051]** The various operations of methods described above may be performed by any suitable means capable of performing the corresponding functions. The means may include various hardware and/or software component(s) and/or module(s), including, but not limited to a circuit, an application specific integrate circuit (ASIC), or processor. Generally, where there are operations illustrated in Figures, those operations may have corresponding counterpart means-plus-function components with similar numbering. For example, blocks 410-440 illustrated in FIG. 4, correspond to circuit blocks 410A-440A illustrated in FIG. 4A.

**[0052]** As used herein, the term “determining” encompasses a wide variety of actions. For example, “determining” may include calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, a database or another data structure), ascertaining and the like. Also, “determining” may include receiving (e.g., receiving information), accessing (e.g., accessing data in a memory) and the like. Also, “determining” may include resolving, selecting, choosing, establishing and the like.

**[0053]** As used herein, a phrase referring to “at least one of” a list of items refers to any combination of those items, including single members. As an example, “at least one of: a, b, or c” is intended to cover: a, b, c, a-b, a-c, b-c, and a-b-c.

**[0054]** The various operations of methods described above may be performed by any suitable means capable of performing the operations, such as various hardware and/or software component(s), circuits, and/or module(s). Generally, any operations illustrated in the Figures may be performed by corresponding functional means capable of performing the operations.

**[0055]** The various illustrative logical blocks, modules and circuits described in connection with the present disclosure may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array signal (FPGA) or other programmable logic device (PLD), discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any commercially available processor, controller, microcontroller or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

**[0056]** The steps of a method or algorithm described in connection with the present disclosure may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module

may reside in any form of storage medium that is known in the art. Some examples of storage media that may be used include random access memory (RAM), read only memory (ROM), flash memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM and so forth. A software module may comprise a single instruction, or many instructions, and may be distributed over several different code segments, among different programs, and across multiple storage media. A storage medium may be coupled to a processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor.

**[0057]** The methods disclosed herein comprise one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is specified, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

**[0058]** The functions described may be implemented in hardware, software, firmware or any combination thereof. If implemented in software, the functions may be stored as one or more instructions on a computer-readable medium. A storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and Blu-ray® disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers.

**[0059]** Thus, certain aspects may comprise a computer program product for performing the operations presented herein. For example, such a computer program product may comprise a computer readable medium having instructions stored (and/or encoded) thereon, the instructions being executable by one or more processors to perform the operations described herein. For certain aspects, the computer program product may include packaging material.

**[0060]** Software or instructions may also be transmitted over a transmission medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of transmission medium.

**[0061]** Further, it should be appreciated that modules and/or other appropriate means for performing the methods and techniques described herein can be downloaded and/or otherwise obtained by a user terminal and/or base station as applicable. For example, such a device can be coupled to a server to facilitate the transfer of means for performing the methods described herein. Alternatively, various methods described herein can be provided via storage means (e.g., RAM, ROM, a physical storage medium such as a compact disc (CD) or floppy disk, etc.), such that a user terminal and/or

base station can obtain the various methods upon coupling or providing the storage means to the device. Moreover, any other suitable technique for providing the methods and techniques described herein to a device can be utilized.

**[0062]** It is to be understood that the claims are not limited to the precise configuration and components illustrated above. Various modifications, changes and variations may be made in the arrangement, operation and details of the methods and apparatus described above without departing from the scope of the claims.

1. A method for wireless communications, comprising: receiving a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses; applying gain values to the pulses to obtain a binary matrix for each gain value; generating a probability vector for each gain value using the binary matrix obtained for that gain value; and generating an output signal using the probability vectors.
2. The method of claim 1, further comprising: determining a range of the gain values; determining a number of different gain values within the range based on a ratio of largest and smallest of the gain values within the range; and determining each gain value within the range based on the number of different gain values, the largest and the smallest gain values within the range.
3. The method of claim 2, wherein the number of different gain values within the range is determined based on a signal-to-noise ratio (SNR) and a variance of the received signal.
4. The method of claim 2, wherein determining the range of gain values comprises: sweeping exponentially a gain value from one period to another period of the received signal until the generated output signal is equal to zero.
5. The method of claim 2, wherein determining the range of gain values comprises: determining the smallest gain value based the received signal; and determining the largest gain value based on the smallest gain value and a defined constant.
6. The method of claim 1, wherein applying the gain values to the received signal comprises: applying one of the gain values for each pulse of the received signal to generate an amplified received signal.
7. The method of claim 6, further comprising: performing one-bit quantization of the amplified received signal.
8. The method of claim 1, wherein elements of the probability vector for each gain value are computed as average values of columns of the binary matrix for each gain value.
9. The method of claim 1, wherein generating the output signal comprises linearly combining the probability vectors.
10. An apparatus for wireless communications, comprising: a receiver configured to receive a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses; an amplifier configured to apply gain values to the pulses to obtain a binary matrix for each gain value; a first generator configured to generate a probability vector for each gain value using the binary matrix obtained for that gain value; and a second generator configured to generate an output signal using the probability vectors.

11. The apparatus of claim 10, further comprising: a first processor configured to determine a range of the gain values; a second processor configured to determine a number of different gain values within the range based on a ratio of largest and smallest of the gain values within the range; and a third processor configured to determine each gain value within the range based on the number of different gain values, the largest and the smallest gain values within the range.
12. The apparatus of claim 11, wherein the number of different gain values within the range is determined based on a signal-to-noise ratio (SNR) and a variance of the received signal.
13. The apparatus of claim 11, wherein the first processor configured to determine the range of gain values comprises: a circuit configured to sweep exponentially a gain value from one period to another period of the received signal until the generated output signal is equal to zero.
14. The apparatus of claim 11, wherein the first processor configured to determine the range of gain values comprises: a first circuit configured to determine the smallest gain value based the received signal; and a second circuit configured to determine the largest gain value based on the smallest gain value and a defined constant.
15. The apparatus of claim 10, wherein the amplifier configured to apply the gain values to the received signal comprises: a circuit configured to apply one of the gain values for each pulse of the received signal to generate an amplified received signal.
16. The apparatus of claim 15, further comprising: a quantizer configured to perform one-bit quantization of the amplified received signal.
17. The apparatus of claim 10, wherein elements of the probability vector for each gain value are computed as average values of columns of the binary matrix for each gain value.
18. The apparatus of claim 10, wherein the second generator configured to generate the output signal comprises a combiner configured to linearly combine the probability vectors.
19. An apparatus for wireless communications, comprising: means for receiving a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses; means for applying gain values to the pulses to obtain a binary matrix for each gain value; means for generating a probability vector for each gain value using the binary matrix obtained for that gain value; and means for generating an output signal using the probability vectors.
20. The apparatus of claim 19, further comprising: means for determining a range of the gain values; means for determining a number of different gain values within the range based on a ratio of largest and smallest of the gain values within the range; and means for determining each gain value within the range based on the number of different gain values, the largest and the smallest gain values within the range.

**21.** The apparatus of claim **20**, wherein the number of different gain values within the range is determined based on a signal-to-noise ratio (SNR) and a variance of the received signal.

**22.** The apparatus of claim **20**, wherein the means for determining the range of gain values comprises:

means for sweeping exponentially a gain value from one period to another period of the received signal until the generated output signal is equal to zero.

**23.** The apparatus of claim **20**, wherein the means for determining the range of gain values comprises:

means for determining the smallest gain value based the received signal; and

means for determining the largest gain value based on the smallest gain value and a defined constant.

**24.** The apparatus of claim **19**, wherein the means for applying the gain values to the received signal comprises:

means for applying one of the gain values for each pulse of the received signal to generate an amplified received signal.

**25.** The apparatus of claim **24**, further comprising:

means for performing one-bit quantization of the amplified received signal.

**26.** The apparatus of claim **19**, wherein elements of the probability vector for each gain value are computed as average values of columns of the binary matrix for each gain value.

**27.** The apparatus of claim **19**, wherein the means for generating the output signal comprises means for linearly combining the probability vectors.

**28.** A computer-program product for wireless communications, comprising a computer-readable medium comprising instructions executable to:

receive a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses;

apply gain values to the pulses to obtain a binary matrix for each gain value;

generate a probability vector for each gain value using the binary matrix obtained for that gain value; and

generate an output signal using the probability vectors.

**29.** A headset, comprising:

a receiver configured to receive a signal transmitted over a wireless channel, wherein the signal comprises a sequence of pulses;

an amplifier configured to apply gain values to the pulses to obtain a binary matrix for each gain value;

a first generator configured to generate a probability vector for each gain value using the binary matrix obtained for that gain value;

a second generator configured to generate an output signal using the probability vectors; and

a transducer configured to provide an audio output based on the generated output signal.

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