DATA COMMUNICATION PROTOCOL IN AN AUTOMATIC METER READING SYSTEM

CLAIM TO PRIORITY

The present application claims priority to U.S. Provisional Patent Application No. 60/500,550, (Attorney Docket No. 1725.161US01), filed on September 5, 2003, and entitled, "DATA COMMUNICATION PROTOCOL IN AN AUTOMATIC METER READING SYSTEM."

RELATED APPLICATIONS

This application is related to commonly assigned U.S. Provisional Application No. 60/500,507 (Attorney Docket No. 1725.173US01), filed on September 5, 2003, entitled, "SYSTEM AND METHOD FOR DETECTION OF SPECIFIC ON-AIR DATA RATE," U.S. Provisional Application No. 60/500,515 (Attorney Docket No. 1725.162US01), filed September 5, 2003, entitled, "SYSTEM AND METHOD FOR MOBILE DEMAND RESET," U.S. Provisional Application No. 60/500,504 (Attorney Docket No. 1725.160US01), filed September 5, 2003, entitled, "SYSTEM AND METHOD FOR OPTIMIZING CONTIGUOUS CHANNEL OPERATION WITH CELLULAR REUSE," U.S. Provisional Application No. 60/500,479 (Attorney Docket No. 1725.156US01), filed September 5, 2003, entitled, "SYNCHRONOUS DATA RECOVERY SYSTEM," U.S. Provisional Application No. 60/500,550 (Attorney Docket No. 1725.161US01), filed September 5, 2003, entitled, "DATA COMMUNICATION PROTOCOL IN AN AUTOMATIC METER READING SYSTEM," U.S. Patent Application No. 10/655,760 (Attorney Docket No. 10145-8011.US00), filed on September 5, 2003, entitled, "SYNCHRONIZING AND CONTROLLING SOFTWARE DOWNLOADS, SUCH AS FOR COMPONENTS OF A UTILITY METER-READING SYSTEM," and U.S. Patent Application No. 10/655,759, (Attorney Docket No. 10145-8012.US00) filed on September 5, 2003, entitled,

"FIELD DATA COLLECTION AND PROCESSING SYSTEM, SUCH AS FOR ELECTRIC, GAS, AND WATER UTILITY DATA," which are herein incorporated by reference.

FIELD OF THE INVENTION

The present invention relates to automatic meter reading systems and, more particularly, to the communication protocol used for the endpoint to reader hop in the automatic meter reading system.

BACKGROUND OF THE INVENTION

Current automatic meter reading (AMR) systems are significantly limited in the information that can be obtained from the meter. Generally the AMR system comprises a reader and an endpoint that is interfaced to a meter. In a typical system, the endpoint obtains the consumption reading from the meter and then bubbles up every few seconds to send that consumption reading, via RF signal, to the reader. Alternatively, the endpoint receives a wake-up tone from the reader that prompts the endpoint to send the consumption reading to the reader.

All that is obtained from this configuration is a single consumption reading from the meter and that reading is based on what meter register the endpoint was programmed with initially at the factory.

As such, there is a need for an AMR system that enables the user of the system to have more access to and more control over the information that the meter and endpoint can provide.

SUMMARY OF THE INVENTION

The present invention is a data communication protocol used between an endpoint and a reader in an automatic meter reading (AMR) system. The communication protocol enables the reader to have a conversation with the endpoint in that the reader can tell the meter what to do, it can reconfigure the meter, it can tell the endpoint to reconfigure the meter, it can request a

specific response, it can request the endpoint to reprogram certain values in both the endpoint and the meter, it can request that the end point get specific information from the meter, return it to the end point, which returns it to the reader, etc.

In a preferred embodiment of the present invention., an automatic meter reading (AMR) system includes a fixed or mobile reader and an endpoint. The endpoint is interfaced to a utility meter and the fixed or mobile reader is capable of communicating with the endpoint via RF communication. In this system the fixed or mobile reader sends a message to the endpoint that includes a response mode direction; the response mode direction from the reader tells the endpoint to respond to the reader either in a mobile network mode or a fixed network mode.

In another embodiment of the invention, the reader uses a single RF communication protocol in communicating with the endpoint whether one-way communication or two-way communication is used. In still another embodiment of the invention, the RF communication between the endpoint and reader occurs through the use of a communication protocol that uses a data link layer that directs all outbound transmissions from the reader to the endpoint to be either Manchester encoded or transmitted as non-return to zero data. In still another embodiment of the invention, the communication protocol includes a transport layer that provides slotting control for all data transferred between the reader and the endpoint. In yet another embodiment of the present invention, the communication protocol utilizes a command and control frame for communication between the reader and endpoint. In still another embodiment of the present invention, a plurality of readers and endpoints are provided. The readers are quasi-synchronized in time to provide a control frame to at least one of the readers.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 depicts a radio-based automatic meter reading system that utilizes the data communication protocol of the present invention.

Fig. 2 is a table containing the physical layer specifications of the reader.

Fig. 3A is a table containing the physical layer specifications of the endpoint at data rate 1.

Fig. 3B is a table containing the physical layer specification of the endpoint at data rate 2.

Fig. 4 is a table containing the physical layer specifications of the endpoint in a one-way AMR system.

Fig. 5 is a diagram of a Manchester encoding structure.

Fig. 6 is an example of a Sequence Inversion Keyed Countdown Timer.

Fig. 7 diagrams the data packet structure.

Fig. 8 diagrams a high power pulse data packet structure.

Fig. 9A diagrams a two-way command and control frame.

Fig. 9B diagrams a one-way command and control frame.

Fig. 10 is a table containing universal command types for the data communication protocol of the present invention.

Fig. 11 is a table containing type specific commands for the data communication protocol of the present invention.

Fig. 12 diagrams command 48 of the data communication protocol, Multiple Ungrouped Endpoint Command.

Fig. 13 diagrams command 49 of the data communication protocol, Vector and Listen Frame.

Fig. 14 diagrams command 50 of the data communication protocol, Multiple Commands to Individual Endpoint.

Fig. 15 is a diagram of the channel spectrum of the system.

Fig. 16 is example of a timing diagram for a staged wakeup sequence for a three cell reuse pattern.

Fig. 17 is an example of a three-cell cellular reuse pattern.

Fig. 18 is an example of a four-cell cellular reuse pattern.

Fig. 19 is an example of a five-cell cellular reuse pattern.

Fig. 20 depicts mobile operation of the system over five channels.

Fig. 21 depicts coverage rings.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a data communication protocol for automatic meter reading (AMR) systems. The protocol is designed to be flexible and expandable enabling both one-way and two-way meter reading in both fixed and mobile meter reading systems.

I. System Components

In an AMR system 100, as depicted in Fig. 1, that is utilized with the present invention, the components generally include a plurality of telemetry devices including, but not limited to, electric meters 102, gas meters 104 and water meters 106. Each of the meters may be either electrically or battery powered. The system further includes a plurality of endpoints 108, wherein each corresponds and interfaces to a meter. Each of the endpoints 108 preferably incorporates a radio receiver/transmitter, e.g., the Itron, Inc. ERT. The system additionally includes one or more readers that may be fixed or mobile, Fig. 1 depicts: (1) a mobile hand-held reader 110, such as that used in the Itron Off-site meter reading system; (2) a mobile vehicle-equipped reader 112, such as that used in the Itron Mobile AMR system; (3) a fixed radio communication network 114, such as the Itron Fixed Network AMR system that utilizes the additional components of cell central control units (CCUs) and network control nodes (NCNs); and (4) a fixed micro-network system, such as the Itron MicroNetwork AMR system that utilizes both radio communication through concentrators and telephone communications through PSTN. Of course other types of readers may be used without departing from the spirit or scope of the invention. Further included in AMR system 100 is a head-end, host processor 118. The host

processor incorporates software that manages the collection of metering data and facilitates the transfer of that data to a utility or supplier billing system 120.

The AMR system 100 and the data protocol is usable in both one-way meter reading and in two-way meter reading. The one-way meter reading system enables the reader to listen to messages sent asynchronously from the endpoint while the two-way meter reading system enables the reader to communicate with and command the endpoint while also enabling the endpoint to respond to the reader.

II. System Protocol

The present communication protocol will be described with reference to the 1430 MHz band that may be utilized within North America, however, it should be understood that any other radio frequency band may be used, as suitable, without departing from the spirit or scope of the invention. The present communication protocol will also be described with reference to the Open Systems Interconnection (OSI) protocol stack of the International Standards Organization which includes: (1) the physical layer; (2) the data link layer; (3) the network layer; (4) the transport layer; (5) the session layer; (6) the presentation layer; and (7) the application layer.

II.A. System Protocol – Physical Layer

The physical layer describes the physical characteristics of the communication. This layer conveys the bit stream through the network at the electrical and mechanical level. It provides the hardware means of sending and receiving data on a carrier. The physical layer specifications for the reader may be found in Fig. 2 wherein: (1) the operational modes; (2) the frequency band; (3) the channel bandwidth; (4) the modulation scheme; (5) the deviation; (6) the encoding; (7) the bit rate; (8) the frequency stability; (9) the minimum reception sensitivity; (10) the transmission power; (11) the preamble length; and (12) the transmission modes are provided.

The physical layer specification for the endpoint in a two-way AMR system, at a first data rate and a second data rate, are found in the tables of Fig. 3A and Fig. 3B, respectively. The specifications provided include: (1) the operational modes; (2) the frequency band; (3) the channel bandwidth; (4) the modulation scheme; (5) the deviation; (6) the encoding; (7) the bit rate; (8) the frequency stability; (9) the minimum reception sensitivity; (10) the minimum preamble length; and (11) the factory default frequency. The physical layer specification for the endpoint in a one-way AMR system is provided, similarly, in the table of Fig. 4. However, it should be understood that any other physical layer specifications may be used, as suitable, without departing from the spirit or scope of the invention.

II.B. System Protocol – Data Link Layer

The data link layer specifies how packets are transported over the physical layer, including the framing, i.e., the bit patterns that mark the start and end of packets. This layer provides synchronization for the physical level. It furnishes transmission protocol knowledge and management. In the present data communication protocol, all outbound data transmissions, i.e., all communications from the reader's central radio to endpoint, are Manchester encoded with the guaranteed transition mid-bit and each data bit encoded as $a_n a_n$(bar). (See Fig. 5 for the Manchester Encoding Structure). Inbound transmissions from the endpoint are either transmitted as Manchester encoded data, identical to outbound transmissions, or are transmitted as NRZ (non-return to zero) data. Selection is based on the value of the MCH flag in the command and control frame.

The data link layer provides a countdown timer. The countdown timer uses Sequence Inversion Keying to represent timer bits. Each system is assigned a 10-bit pseudo noise (PN) sequence (for valid sequences, see Table 1 below). That sequence in the data stream represents a timer bit value 0 and the inverse of that sequence in the data stream represents a timer bit value 1. Timer values are composed of 10 timer bits, or 100 data bits. The countdown timer begins at

1023, or 1111111111 binary, and counts sequentially to zero, encoding all timer bits as either the system PN sequence or its inverse. The total counter time, in seconds, is 102400/r, where r is the bit rate, in bits per second. Fig. 6 provides an example of a Sequence Inversion Keyed Countdown Timer.

Table 1. PN Sequences

Sequence Number	Usage	Sequence=0	Inverted Sequence=1
0	Factory Default	0000000010	1111111101
1	Electric Devices	0000000110	1111111001
2	Electric Devices	0000001010	1111110101
3	Electric Devices	0000001110	1111110001
4	Electric Devices	0000011010	1111100101
5	Electric Devices	0000010110	1111101001
6	Electric Devices	0000111010	1111000101
7	Battery Devices	0000101110	1111010001
8	Battery Devices	0001110110	1110001001
9	Battery Devices	0001101110	1110010001
10	Battery Devices	0000011110	1111100001
11	Battery Devices	0001011110	1110100001
12	Battery Devices	0001111010	1110000101

All inbound packet transmissions are preceded by a 24-bit or 25 bit preamble and appended with a 16-bit CRC code, which is inclusive of all header information, but not the preamble, length, or length_bar bytes. The CRC polynomial is 0x1021. The CRC initialization value is 0x0000. CRC processing is performed most significant byte (MSB) first, and the final checksum is not inverted.

II.C. System Protocol – Network Layer

The network layer specifies how packets get from the source network to the destination network. This layer handles the routing of the data (sending it in the right direction to the right destination on outgoing transmissions and receiving incoming transmissions at the packet level). The network layer does routing and forwarding. In the present data communication protocol, the

network layer functionality is only implemented in electric endpoints, i.e., it is not used for battery-powered endpoints, or in any endpoint that acts as translator or repeater. This layer controls the hopping functions that need to occur between a reader and any endpoint in order to transfer data. This hopping protocol is currently used within the Itron AMR systems and is therefore not described in detail herein.

II.D. System Protocol– Transport Layer

The transport layer is used to solve problems like reliability ("did the data reach the destination?") and ensure that data arrives in the correct order. This layer manages the end-to-end control (for example, determining whether all packets have arrived) and error-checking. It ensures complete data transfer. In the present data communication protocol, slotting control is handled in the transport layer. This includes slot assignments, timing, and any necessary packetization. Fig. 7 details the packet structure. The message, message type, and flags are received from the presentation layer, and broken into appropriately sized packets. Each packet is prefaced with the endpoint ID, flags, message type, endpoint type, and packet length. The packet length reflects the number of bytes in the message itself, exclusive of header information. In the case where more than 254 bytes are required in a packet, the value of the length field is set to 0xFF, and the actual length of the message structure is placed in bytes 14 (high byte) and 15 (low byte), with the message bytes to follow. All packets must have a whole number of bytes in the message.

The packet number byte, when used as part of the message, is configured as below in Table 2, wherein the first four bits comprise the total number of packets in this message and the last four bits comprise the packet number.

Table 2. Packet Number

T	T	T	T	N	N	N	N
MSB							LSB

The flags byte is configured as below in Table 3. The first two bits are reserved while the second two bits provides the encoder number (for multi-encoder units), wherein 00 = encoder 0, 01 = encoder 1, 10 = encoder 2, and 11 = encoder 3. The fifth bit signifies the status of a pending event, wherein 0 = no pending event and 1 = a pending event. The sixth bit comprises the security bit, wherein 0 = security disabled and 1 = security enable. The seventh bit comprises the relay bit, wherein 0 = message from originating endpoint and 1 = message via relay. The eighth bit comprises the resend bit, wherein 0 = first attempt at packet transmission and 1 = resend attempt.

Table 3. Flags

R	R	ENC	ENC	EVT	SEC	RLY	RSD
MSB							LSB

Some endpoints in the system have the option of sending out an infrequent (several times a day) fixed format message at a higher power level, for use in 1-way fixed network applications. The message has its own structure, as defined in Fig. 8. The custom packet is then BCH (255, 139, 15) encoded, prior to transmission. The encoding polynomial is $0x46140713206017556157072273024745356744 5_8$. For multi-encoder endpoints this packet is generated and sent for each individual encoder. The flags for the high power pulse data packet structure are configured as shown in Table 4 below. The first four bits are reserved while the fifth and sixth bits provide the encoder number, wherein 00 = encoder 0, 01 = encoder 1, 10 = encoder 2, and 11 = encoder 3. The seventh bit comprises the relay bit, wherein 0 = message from originating endpoint and 1 = message via relay. The eighth bit comprises the error code indicating that a critical endpoint error has occurred.

Table 4. Flags

R	R	R	R	ENC	ENC	RLY	ERR
MSB							LSB

The endpoints may also be set to send out any preprogrammed message type in place of the fixed format message described above.

II.E. System Protocol – Session Layer

The session layer sets up, coordinates, and terminates conversations, exchanges, and dialogs between the applications at each end. It deals with session and connection coordination. In the present data communication protocol, the session layer generally comprises the command and control frame that is sent from the reader to the endpoint.

II.E.i. System Protocol – Session Layer/Two-Way Command and Control

The command and control frame is used to issue command to two-way endpoints either individually or in groups. It also serves to realign the endpoint real-time clock. Fig. 9A diagrams the two-way communication command and control frame. As shown, the command and control frame transmission is preceded by a 24-bit preamble, as indicated by the three "P" fields within the frame. The first 16 bits are preferably an alternating pattern, AAAAh, and are used for clock recovery. The last 8 bits are used for frame and timing synchronization.

Field "0" of the command and control frame comprises the system identification (ID). Each system is issued an 8-bit ID value, which is stored in the endpoint, to distinguish different systems within geographic proximity. The endpoints are designed to respond to commands from their own system or to commands that address them specifically by ID number, proper security password, and have a 0x00 in field "0". The system ID functions nearly identically to the cell ID, described below. However, the system ID is universal, while the cell ID is local, i.e., a single system will have multiple cells each having the same system ID but a different cell ID.

Field "1" of the command control frame comprises the frame ID. Each reader within the system is assigned a frame ID to use based on its position in the wake-up sequence. The position in the wakeup sequence is directly related to the frequency reuse pattern that is used in a given

system. Table 1, described earlier, correlates the frame ID to the channel, which is correlated to the cell reuse ratio.

Field "2" of the command and control frame comprises the cell ID. Each cell is issued an 8-bit ID value, which is stored in the endpoint, to distinguish different systems within geographic proximity.

Fields "3" through "6" of the command and control frame is the RTC, which is defined as UTC time (coordinated universal time), which is a 32-bit value representing the number of seconds since midnight (00:00:00) on January 1, 1970 GMT.

Field "7" is the command flags 1 field, wherein the first three bits define a slot length according to Table 5.

TABLE 5. Slot Lengths

Value of Length Bits	Nominal Length in Ticks*	Nominal Length in ms
000	819	24.99390
001	1638	49.98779
010	3277	100.00610
011	6553	199.98169
100	9830	299.98780
101	16384	500.00000
110	32768	1000.00000
111	163840	5000.00000

*Defined as ticks of an ideal 32,768 Hz clock.

The fourth bit is the forward error correction bit, wherein 0 = no forward correction error and 1= forward error correct all responses. The fifth bit provides the slot mode, wherein 0 = respond to command in pseudo-random slot (Slotted Aloha) and 1 = respond to command in the defined slot. The sixth bit of field "7" defines the data type, wherein 0 = NRZ response from endpoint and 1 = Manchester encoded from the endpoint. The seventh and eighth bits of field "7" comprise the command target, wherein 00 = the entire cell, 01 = the group defined in EPID_HI (field "12"), 10 = the group defined in EPID_LO (field "15"), and 11 = the endpoint defined by EPID (including HI/LO), fields "12" through "15". It should be noted that in single endpoint communications the command target (TGT) is set to 11 and the endpoint responds immediately

after command processing with a minimum of 25 milliseconds between this frame and the endpoint response.

Field "8" of the command and control frame is the command flags 2 field, wherein the first four bits are reserved. The fifth and sixth bits defined the encoder number, wherein 00 = Encoder 0, 01 = Encoder 1, 10 = Encoder 2, and 11= Encoder 3. The final seventh and eighth bits define the transmit mode, wherein 00 = transmit mode 1, e.g., mobile response required, 01 = transmit mode 2, e.g., fixed network response required, and 10/11 are reserved. Also see section V below.

Field "9" of the command and control frame comprises the slot offset. Slot offset defines the number of slots between packets in multi-packet messages. For example, if the endpoint has an initial slot number of 50, and the slot offset is 120, a three-packet message would be transmitted in slots 50, 170, and 290.

Fields "10" and "11" of the command and control frame define the first unsolicited message. Specifically, they define the slot number where the unsolicited messages (UMs) are to begin. Any UMs generated during the cell read would be reported in a pseudo-randomly selected slot after the slot defined here. If the value of this field is 0x0000, no UMs are sent from the endpoint.

Fields "12" through "15" of the command and control frame provide the endpoint IDs for those endpoints that the reader is desiring to communicate with.

Fields "16" and "17" are the security fields and are described further in relation to the presentation layer.

Field "18", defines the command set. The commands are divided into two groups: (1) universal and (2) type-specific. Universal commands are numbered 0-63 and are applicable to all the system endpoints. Type specific commands are numbered 64-255 and vary depending on the lower nibble of the command set field in accordance with Table 6 below.

Table 6. Command Sets

Command Set	CDS Value	Usage
0 (default)	0000	Utility Metering Endpoints
1	0001	Repeaters and Translators
2	0010	Telemetry Devices
3-14	0011-1110	<<Reserved>>
15	1111	<<Reserved Engineering Use Only>>

Fields "19" through "21" of the command and control frame define the command and command body. Specifically, the eight command bits of field "19" indicate the command type, wherein the numbers 0-63 are universal commands and 64-255 are the type specific commands. Fields "20" and "21" provide sixteen bits wherein any data needed to carry out the command type is provided. The tables in Figs. 10 and 11 indicate the command types and command bodies that are possible with the system of the present invention. Referring to the universal commands (Fig. 10), it can be seen that the present system is capable of but not limited to: (1) reporting a status; (2) changing a system number to a new system number; (3) changing a group number to a new group number; (4) changing a system slot number to a new system slot number; (5) changing the cell ID to a new cell ID; (6) reporting slot numbers; (7) resending identified packets of data; (8) setting the receiver bubble-up period; (9) setting the bubble-up channel; (10) setting the bubble-up time; (11) configuring the transmission power; (12) setting the channel frequency; etc.

Referring to the type specific commands (Fig. 11), numerous other commands are available including but not limited to: (1) reporting consumption data; (2) reporting time of use (TOU) data; (3) reporting logged data; (4) reporting temperature; (5) reporting tamper data; (6) setting configuration flags; (7) initializing consumption; (8) reporting an event summary; (9) performing an endpoint diagnostic check; (10) reporting memory contents; etc.

Fields "22" and "23" of the command and control frame designate the response frequency for the endpoint. The response frequency is configured as 16 bit flags, identifying valid response frequencies for the endpoint. For example, if the response frequency has a value

of 0x00C1 (bits, 7, 6, and 0 are set), the endpoint may respond on channel, 7, channel 6, or channel 0.

Field "24" is reserved for later use.

Field "25" indicates the length of the extended control frame in bytes. A value of 0 indicates that no extended frame is present.

Fields "26" and "27" of the command and control frame provides the cyclic redundancy check (CRC). Specifically, fields "26" and "27" provide a 16-bit CRC. The CRC is preferably a polynomial defined as 0x1021. The CRC initialization value is 0x0000. CRC processing is performed most significant bit (MSB) first, and the final checksum is not inverted.

II.E.ii. System Protocol – Session Layer/One-Way Command and Control

For simplicity one-way devices may opt to use the programming frame shown in Fig. 9B. The command and command body bytes are similar to that described above with reference to the two-way devices. The byte for number of commands provides the total number of commands to follow in this frame, with a maximum value of 8. The command flags are diagrammed in Table 7 below. The first two bits indicate the transmit mode, wherein 00 = transmit mode 0, 01 = transmit mode 1, and 10/11 are reserved. The third bit designates the data logging, wherein 0 = data logging is disabled and 1 = data logging is enabled. The fourth bit designates the forward error correction, wherein 0 = disable forward error correction on response and 1 = enable forward error correction on response. The fifth and sixth bits designate the mode set, wherein 00 = stock mode, 01 = test mode, 10 = reserved mode, and 11 = normal mode. The seventh and eighth bits are reserved.

Table 7. Command Flags

TXM	TXM	DLG	FEC	MDE	MDE	R	R
MSB							LSB

II.E.iii. System Protocol – Session Layer /Special Commands – Channel Frequency

Certain of the commands provided in the command and control frame are described in detail below. For instance, Command 33, which is the set channel frequency. Each of the system endpoints support up to 16 channels, which are set individually. They may or may not be contiguous channels. The channel numbering differs based on frequency band. For example, in the present implementation of the invention, the 1427 – 1432 MHz band is divided into 6.25 kHz frequency channels, with frequency channel 0 centered at 1427.000 MHz, frequency channel 1 centered at 1427.00625 MHz, etc. If endpoint channel 15 is programmed to a value of 480, that endpoint receiver will always operate at 1427.000 + (.00625 * 480) = 1430.000 MHz. This may be extended to other frequency bands. For example, the 433-435 MHz band is divided into 25 KHz frequency channels with the frequency channel 0 centered at 433.000 MHz, frequency channel 1 centered at 433.025 MHz and so on.

The command body of the set channel frequency command is detailed below in Table 8:

TABLE 8. Command Body/Channel Frequency

CHN	CHN	CHN	CHN	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ
MSB															LSB

Individual frequencies are programmed into the endpoint by selecting the channel being programmed (1-15) with the top nibble, and the frequency number in the lower 12 bits. Endpoint channel 0 is preferably the manufacturing default frequency, and may not be edited. Endpoint channel 15 is the receiver frequency. It is initialized to the same frequency as channel 0 at manufacture, and is preferably programmed prior to or at installation. The endpoint channel uses are defined in Table 9 below:

Table 9. Endpoint Channel Use

Endpoint Channel	Channel Use
0	Factory Default. This channel is not reprogrammable.
1	General use Tx/Rx (Transmission/Reception)
2	General use Tx/Rx
3	General use Tx/Rx

4	General use Tx/Rx
5	General use Tx/Rx
6	General use Tx/Rx
7	General use Tx/Rx
8	General use Tx/Rx
9	General use Tx/Rx
10	General use Tx/Rx
11	General use Tx/Rx
12	General use Tx/Rx
13	General use Tx/Rx
14	Default UM Channel (unsolicited message)
15	Default Rx Channel

The configuration flag commands, i.e., commands 90, 91, and 92 are used for setting individual flags in the endpoints. Each flag command includes an 8-bit flag mask and an 8-bit flag as shown below (the configuration flags 1 command body):

Table 10. Flag Mask

MSK	MSK	MSK	MSK	MSK	MSK	MSK	MSK
MSB							LSB

Table 11. Flags

R	R	R	TxB	UMC	FN	FEC	MMI

The flag mask field determines which flags are to be modified by this command. A "1" in any bit position means the associated value in the flags field should be modified. For example, A value of 0x17 (bits 4,2,1 and 0 are high) means that the values in the Flags field, bits 4, 2, 1, and 0 must be written to the associated flags in the endpoint. With regard to the flags field of Table 7, the first three bits are reserved for future growth while the fourth bit, TxB, determines if the endpoint is in transmit bubble up mode, the fifth bit, UMC, defines the unsolicited message channel, i.e., UMC = 0 then transmit UMs on Channel 14, and UMC = 1 then transmit UMs on channel 15. The sixth bit of the flags field defines the fixed network mode, wherein 0 = this endpoint operates in Mobile/Handheld mode only and 1= this endpoint operates in mobile/handheld/fixed network mode. The seventh bit of the flags field defines the forward error correction, wherein 0 = no forward error correction applied to the high power pulse and 1 =

forward error correction is applied to the high power pulse. The eighth bit of the flags field defines the multiple message integration, wherein 0 = no multiple message integration applied to high power pulse and 1 = multiple message integration applied to high power pulse.

II.E.iv. System Protocol – Session Layer/Special Commands – Test Commands

The present data communication protocol provides at least two commands for use in system testing and analysis. The first command is command 210, i.e., Generate UM (unsolicited message). This command automatically generates an unsolicited message in all endpoints addressed by the command and control frame. It generates the lowest numbered UM supported by the endpoint. The second command is command 211, i.e., Enter Screaming Viking Mode. Screaming Viking Mode is a constant transmission mode, to be used for test only. When this command is received, the endpoint repetitively transmits its ID for the number of minutes declared in the command. If a value of 0 is sent, the mode is active for 15 seconds.

II.E.v. System Protocol – Session Layer/Special Commands – Extension Commands

Commands 48, 49, 50 and 51 of the data communication protocol are implemented as extensions to the command and control frame. The extension commands immediately follow the command and control frame in the same transmit session. Command 48 is the multiple ungrouped endpoint command. In the case where the system needs to command a group of specific endpoints and vector them to specific slots, command 48 is issued. The central radio then issues commands to these endpoints, as shown in Fig. 12. This command can be used to address a maximum of 16 distinct endpoints. The packet length reflects the number of endpoints addressed by the message. Note that the command 48 may not be used for any command that requires the security password. The structure of command 48 provides for an 8-byte preamble having the value of 0xAAAA AAAA AAAA AA96, the length, the endpoint IDs, and the

command bodies for each of the endpoints and a response byte for each of the endpoints. The response byte is diagrammed in Table 12 below:

Table 12. Response Byte

R	R	R	R	CHN	CHN	CHN	CHN
MSB							LSB

The response byte reserves the first four bits and utilizes the last four bits to define the response frequency nibble. Specifically, the four bit flags define which of the pre-programmed channels the endpoint may respond on. If CHN = 0000, then use the response frequency byte from the original command and control frame. The structure of the command 48 also includes the CRC as described earlier.

Command 49, i.e., the vector and listen frame, is issued in the instance where the central radio or reader need to download an arbitrary block of data to the endpoint. The endpoint, upon receiving this command receives a data frame, as defined in Fig. 13. This command is valid only when the endpoints are individually addressed (i.e., TGT = 11). The data is endpoint-type specific. Note that the vector and listen frame has an 8-byte preamble with a value of 0xAAAA AAAA AAAA AA96. Further, note that the packet length reflects the number of bytes in the message itself, exclusive of header information, and that the CRCs computed over all bytes in the message body.

Command 50, the multiple command to individual endpoint command, is used in the case where the central radio or reader need to download a series of commands to one specific endpoint. The endpoint, upon receiving this command, receives a data frame as defined in Fig. 14. This command is only valid when the endpoints are individually addressed (i.e., TGT = 11). Up to 24 commands may be issued to an endpoint using this structure. Note that the packet length reflects the number of commands to be issued within this structure.

Command 51, the Extended Frame Mobile Read command, uses the multiple ungrouped endpoint command structure, with a Slotted-ALOHA period between the extended frame and the queried response slots. All endpoints which recognize the command respond. If the endpoint is among those addressed by the extended frame, it responds as commanded, being offset by 16 slots. If the endpoint is not specifically addressed it responds in the Slotted-ALOHA section with its programmed default message.

II.F. System Protocol – Presentation Layer

The presentation layer, which is usually part of an operating system, converts incoming and outgoing data from one presentation format to another and it is sometimes called the syntax layer. In the present data communication protocol, the presentation layer handles data security and any necessary data compression and decompression.

The data security is preferably a simple two-level protocol, which may be enabled or disabled by the customer. Level 1 provides simple encryption for the transfer of normal data while level 2 provides write security to the endpoint to prevent unauthorized users from changing endpoint parameters.

Level 1 is intended for use on ordinary data being transmitted from the endpoint to the head end. All data is encrypted with a simple 8-bit XOR mask. The level 1 security enables flag and encryption mask and are editable by a level 2 parameter write. The factory default for the XOR mask is the bottom 8 bits of the serial number. Level 1 security is applied only to the message itself and not to the EPID, flags, or message type. Level 1 security may be disabled by setting the mask value to 0.

Level 2 security is intended for use on any head end commands to change endpoint parameters. It includes modification of operational, security and reprogramming parameters. Level 2 functionality is independent and can be applied with or without Level 1 functions enabled. Each endpoint has a 16-bit password. This password is originally defined at install,

and can be edited by a valid Level 2 command. Any write command must include the current password to be considered valid by the endpoint. For added security, the Level 1 encryption mask may be applied to the password, if Level 1 functionality is active. There is no compression performed on packet data.

II.G. System Protocol – Application Layer

The application layer is the layer at which communication partners are identified, quality of service is identified, user authentication and privacy are considered, and any constraints on data syntax are identified. (This layer is *not* the application itself, although some applications may perform application layer functions.) In the present data communication protocol, an endpoint application layer is used in conjunction with the application programming interface (API). When data is requested by the presentation layer, via the API, the application layer performs its processing and returns the requested message as a single block, along with one 8-bit value. The value represents the message type.

III. System Operation

The two-way AMR system of the present invention, at 1430 MHz, is designed to operate most efficiently in five contiguous RF channels. This allows the use of a cheaper (wider) receiver section in the endpoint while still maintaining the FCC mandated 50 KHz maximum transmit spectrum. The transmit spectrum in all devices, endpoints, and readers, must maintain a 50 KHz or less occupied bandwidth during transmit. The receiver in the reader must also have a good selectivity on the channel of interest. The endpoint receiver is allowed to accept a wider receive bandwidth primarily to reduce the cost of the endpoint.

Refer to Fig. 15 to observe the 250 KHz of spectrum allocated to the system. As shown, the spectrum is divided in to five 50 KHz channels. The center channel, i.e., channel 3, is designated as the control channel for the system 100. All endpoints 106 listen on this channel.

As such, if the readers are quasi-synchronized in their outbound transmissions the center channel approach allows the endpoints to use a wider receive bandwidth while avoiding the interference that would normally be a problem (synchronization is described in further detail below). The diagram of Fig. 15, illustrates the bandwidth differences graphically. Since the reader has good selectivity the endpoints can respond on a different channel in each cell simultaneously allowing the maximum data throughput in the system (cell re-use is described in further detail below).

By utilizing an appropriate RF ASIC, the architecture can be reduced to three contiguous channels with the reaming two or more channels scattered throughout the band to ease spectrum allocation requirements. With a reduction in the interference protection to the end point, a completely separated channel model could be used in an alternative configuration. However, in the separate channel model, the endpoint requires additional base band filtering and is still slightly more susceptible to adjacent channel interference on the control channel especially if operating in the high power portion of the band. The separate channel option also allows multiple control channels in the system when mobile operation is used with multiple outbound channels. When using the separate channel model, channels 2 and 4, of a 5-channel block, are used for control signals.

To alleviate cell-to-cell interference in a system with a single control channel the readers must be synchronized in time so that the control frames, which are described in further detail below, do not overlap. The addition of "dead time" in between sequential control frames allow for the receivers to be quasi-synchronized instead of in perfect lock step. In the preferred embodiment, quasi-synchronized means that the receivers are within 0.5 seconds of each other, which can easily by achieved via protocols such as NTP (network time protocol). Other quasi-synchronization times may be used without departing from the spirit or scope of the invention. As such, a GPS or other high accuracy time base is not required within the readers.

Within the AMR system, each reader is assigned a frame ID to use based on its position in a wakeup sequence. The position in the wakeup sequence is directly related to the frequency

reuse pattern used in a given system. The timings in the diagram of Fig. 16 are provided as an example of a staged wakeup sequence for three cell reuse. As shown, the timings are for an endpoint to endpoint clock accuracy of +/- 0.5 seconds, if the value obtainable is only +/- 1 second then the dead time must be increased to 5 and the nominal frame time to 22.5 seconds. All other timings remain the same. If GPS is available in the reader, the dead time can be reduced and the time frame timing can be shortened. In any case, the minimum dead time is preferably 0.5 seconds.

As shown in Fig. 16, the first wake-up sequence is initiated at time T=0. For the first 18.5 seconds, get wakeup (SIK countdown timer), next 0.25 seconds (command and control, frame 2), and last 2.5 second is dead time. The remaining time in the timeline is the hold off time for response slots, which is the frame number * the nominal frame time, or 2*20 = 40 seconds of hold off time. At T=20, the second wake-up sequence is initiated. Similarly, the first 18.5 seconds, get wakeup (SIK countdown timer), next 0.25 seconds (command and control, frame 1), and the last 2.5 seconds is dead time. The hold off time for response slots in this instance is, again, the frame number * the nominal frame time, which is 1*20 = 20 seconds off hold off time. At T=40, the third wake-up sequence is initiated. For the first 18.5 seconds, get wakeup (SIK countdown time), the next 0.25 seconds (command and control, frame 0), and the last 2.5 seconds is dead time. The hold off time for response is calculated as follows, frame number * nominal frame time, or 0*20 = 0 seconds hold off time meaning the endpoints have 2.5 seconds before the beginning of slot 0 in this cell.

As mentioned, the example of Fig. 16 is for a three cell reuse pattern. However, the example can be easily extended to higher cellular reuse ratios by adding more frames as appropriate. In the 1430 MHz system, the maximum recommended cellular reuse is 5. This leads to a hold off time of 100 seconds in the first cell transmitted which is short enough for the endpoint to maintain accurate timing with regard to slot timings.

Unless otherwise specified by the system, the frame ID is preferably tied to the cellular frequency used based on Table 13 below:

Table 13. Frame ID

Cell Reuse Ratio	Channel to Frame ID mapping
3 Cell	Channel 1 = Frame ID 0 Channel 3 = Frame ID 1 Channel 5 = Frame ID 2
4 Cell	Channel 1 = Frame ID 0 Channel 2 = Frame ID 1 Channel 4 = Frame ID 2 Channel 5 = Frame ID 3
5 Cell	Channel 1 = Frame ID 0 Channel 2 = Frame ID 1 Channel 3 = Frame ID 2 Channel 4 = Frame ID 3 Channel 5 = Frame ID 4

To maximize throughput in the system 100, a cellular reuse scheme is employed in the 1430 MHz band. The reuse ratio is preferably a 3, 4, 5, 7, or 9 cell pattern. Smaller patterns are preferred from a delay perspective, however, the final choice is preferably made during the RF planning and installation of actual systems in the field. The 7 and 9 patterns are preferably used in the virtual cell model. The reuse patterns are provided in Figs. 17, 18, and 19 depicting three-cell (ABC), four-cell (ABCD), and five-cell reuse patterns (ABCDE), respectively.

IV. Mobile and Hand-Held Operation

When operating in the mobile or hand-held mode, the 2.5 seconds of "dead time" does not apply. Rather slot "0" occurs at the end of the command and control frame plus 25 milliseconds. Note, that due to time required to read the attached meter and/or bring the charge pump to full operation the endpoint may or may not respond in slot "0" even if told to respond immediately.

In programming mode, the hand-held control may reduce its sensitivity by as much as 30 dB to avoid overload conditions at close programming distances. The hand-held and endpoint

must work with programming distances as close as 0.5 meters and as far as 300 meters when in the mobile mode of operation with a line of site propagation path.

In mobile operation the wake-up sequence, the command & control data, and the receive portions of a standard read cycle are continuously repeated as the mobile moves through the system. The timing is preferably in the range of a one to five second cycle. The diagram depicted in Fig. 20 gives a general over view of the mobile operation over the five channels.

The command & control frame preferably contains a group call read that solicits a consumptive type reading from all of the endpoints that can hear the mobile and that have the correct system ID. The endpoint responds to the group call in a random slot, on a random channel. The random channel is chosen from the list of available channels that is provided in the command & control frame. The random slot is one of the 50 ms slots in the Slotted-ALOHA portion of the frame. (Slotted ALOHA is a random access scheme just like regular ALOHA except that the transmissions are required to begin and end within the predefined timeslot. The timeslots are marked from the end of the command & control frame just like in the fixed network).

When the reader hears a response from a given endpoint, it knows that it is within range and can request a specific response from the endpoint in the next command & control frame. The command & control frame is expected to contain both a standard command frame and an extended control frame to allow for the mobile to access the most endpoints possible in a single pass. When the mobile requests a response from the end point it will tell it the channel and time slot that it is supposed to respond on. This is to minimize the chances of a collision on the longer messages that can be delivered in the MDP type of responses. During the mobile cycle, battery endpoints may be required to bubble up their receivers up at a higher rate than normal or synchronize to the first command & control frame to improve mobile performance.

If the van is moving at a maximum of 30 miles per hour it will travel 440 feet in 10 seconds. The van will also have a communications radius of approximately 500 feet give a 1400

MHz system operating at a data rate of 22.6 Kchips/second, with the expected power levels and receiver sensitivities (e.g., +14 dBm endpoint TX power, -110 dBM RX sensitivity in the van, 20 dB margin, endpoint at 5'). The margin is included because the MDP data packet is much longer than the current SCM type messages and is not repeated unless an error occurs. To achieve a low re-try rate, it is desirable to bring the BER down to 0.01%. To do this under normal situations would require an additional 20 dB of margin, however, a diversity setup on the van receivers can be used to achieve the same results. This requires two antennas on the van placed five to six feet apart along with an additional receiver demodulator chain per channel. For SCM data that is repeated multiple times, the system can operate at a much lower margin and still achieve excellent read reliability in the van. A coverage radius of about 1200 feet is obtained for the system when collecting standard consumptive data.

The diagram of Fig. 21, shows the coverage rings for low margin SCM messages and for the 20 dB margin IDR messages for the present system in comparison with the current 0 dB margin SCM messages from the ERT.

With the current mobile protocol each endpoint is, on average, in the range of the van for approximately 12 to 25 seconds. This is an appropriate amount of time to wake up the endpoint, identify who it is, request an MDP (mobile data packet = 250 bytes of raw data maximum) to be sent, receive the MDP and potentially retry the request and receive portions of the process if necessary.

In the basic system, there are five channels at a maximum 75% utilization for MDP responses. This gives an effective data rate of 42375 BPS or 5296 bytes per second or 21 blocks per second. Since the system is looking at a single block per meter, the system can support 21 new meters per second. The mobile then has a nominal range of 500 feet. This gives the system of about 175 meters in range at any given time, even in the densest specified systems. If the van is moving at 30 mph, the system gets 44 feet of new meters per second. In performing a geometric approximation, the result is about 12 new meters per second. So, the system can

handle 21 new meters per second but can only get in the range of 10 to 12 meters per second. This allows for a full set of retries in a dense system. (This assumes the low 11.36363 KBPS data rate and the full 250 byte MDP, for smaller packets and with the higher data rate option, the situation is even better.

V. Response Optimization for Mobile and Fixed Network Operation

In order to optimize the batter efficiency, range, and overall system robustness for endpoints that must operate in both a mobile and fixed network scenario without reprogramming, the following methodology is preferably used. The outbound transmission from the reader includes a flag that states the response mode of the endpoint. When the response mode flag is set to "mobile" the endpoint responds at a lower power (e.g., +14dBm) and in a dynamically randomized slot determined as described above. When the endpoint sees the "fixed network" flag set it responds in its assigned slot at high power (e.g., +30 dBm). The advantage provided by this scenario is that in the mobile case the reader is not burdened with slot dynamic allocation of multiple, which can be computationally intensive and consume additional air time to successfully communicate to all the in-range endpoints. It also allows the endpoint to conserver power and reduce interference. This leads to the ability to transmit more data with less retries. In the fixed network case, the high power mode enables the system to get maximum range from the device (reducing infrastructure costs) while interference is mitigated by assigned slots. The slots are efficiently assigned in the fixed network case because of the pseudo-static nature of the system. Note that prior art systems enabled only static programming of the endpoint to operate in one mode or the other. As such, the previous methodology did not allow for mixed mode operation without reprogramming the endpoint. Thus, the present invention presents the combination of low power operation and dynamic slot assignment for mobile operation with the high power slotted operation for the fixed network all controlled by a flag in the outbound

wakeup data. Refer to field "8," bits 7 and 8, of the command & control frame that define the transmit/response mode.

The present invention may be embodied in other specific forms without departing from the spirit of the essential attributes thereof; therefore, the illustrated embodiment should be considered in all respects as illustrative and not restrictive, reference being made to the appended claims rather than to the foregoing description to indicate the scope of the invention.

CLAIMS

1. An automatic meter reading (AMR) system, comprising:

a fixed or mobile reader

an endpoint interfaced to a utility meter, wherein said fixed or mobile reader is capable of communicating with said endpoint via RF communication; and

wherein said fixed or mobile reader sends a message to said endpoint that includes a response mode direction for said endpoint to respond to said reader in either a mobile or a fixed network mode.

2. The AMR system of claim 1, wherein the mobile response mode direction directs said endpoint to respond to said reader at a low power and in a dynamically randomized slot.

3. The AMR system of claim 1, wherein the fixed network response mode direction directs said endpoint to respond to said reader at a high power and in an assigned slot.

4. The AMR system of claim 2, wherein the fixed network response mode direction directs said endpoint to respond to said reader at a high power and in an assigned slot.

5. An automatic meter reading (AMR) system, comprising:

a reader;

an endpoint interfaced to a utility meter, wherein said reader is capable of communicating with said endpoint via RF communication; and

wherein said reader uses a single RF communication protocol in communicating with said endpoint via one-way communication or two-way communication.

6. The AMR system of claim 5, wherein one-way communication enables said endpoint to communicate with said reader and deliver a specified message type.

7. The AMR system of claim 5, wherein two-way communication enables said reader to communicate with said endpoint, command said endpoint, and enable said endpoint to respond to said reader.

8. The AMR system of claim 6, wherein two-way communication enables said reader to communicate with said endpoint, command said endpoint, and enable said endpoint to respond to said reader.

9. An automatic meter reading (AMR) system, comprising

a reader;

an endpoint interfaced to a utility meter, wherein said reader is capable of communicating with said endpoint via RF communication;

wherein said RF communication occurs through the use of a communication protocol, and wherein said communication protocol includes a data link layer directing all outbound data transmissions from said reader to said endpoint to be Manchester encoded and directing all inbound transmissions from said endpoint to said reader to be either Manchester encoded or transmitted as non-return to zero data.

10. The AMR system of claim 9, wherein said data link layer provides a sequence inversion keyed (SIK) countdown timer.

11. An automatic meter reading (AMR) system, comprising

a reader;

an endpoint interfaced to a utility meter, wherein said reader is capable of communicating with said endpoint via RF communication;

wherein said RF communication occurs through the use of a communication protocol, and wherein said communication protocol includes a transport layer, wherein said transport layer provides a slotting control for all data transferred between said reader and endpoint.

12. The AMR system of claim 11, wherein said slotting control includes slot assignments, timing, and packetization of said data.

13. The AMR system of claim 12, wherein a packet of packetized data includes a packet number, an ID, a flag, a message type, a message, and an endpoint type.

14. An automatic meter reading (AMR) system, comprising

a reader;

an endpoint interfaced to a utility meter, wherein said reader is capable of communicating with said endpoint via RF communication;

wherein said RF communication occurs through the use of a communication protocol, and wherein said communication protocol includes a command and control frame.

15. The AMR system of claim 14, wherein command and control frame issues commands to said endpoint.

16. The AMR system of claim 14, wherein said command and control frame issues realigns a real-time clock within said endpoint.

17. The AMR system of claim 14, wherein said command and control frame includes a command set field.

18. The AMR system of claim 15, wherein said command set includes universal commands and type specific commands.

19. The AMR system of claim 14, wherein said command and control frame includes a command body, wherein said command body provides a command selected from a group consisting of:

reporting a status of said endpoint;

changing a system number of said endpoint;

changing a group number of said endpoint;

changing a system slot number of said endpoint;

changing a cell ID of said endpoint;

providing a reporting slot number to said endpoint;

requesting resending of identified packets of data from said endpoint;

setting a bubble-up channel of said endpoint;

configuration a transmission power of said endpoint; or

setting a channel frequency of said endpoint.

20. The AMR system of claim 14, wherein said command and control frame includes a command body, wherein said command body provides a command selected from a group consisting of:

requesting a report of consumption data from said endpoint;

requesting a report of time of use data from said endpoint;

requesting a report of logged data from said endpoint;

requesting a report of tamper data from said endpoint;

setting a configuration flag within said endpoint;

initializing consumption within said endpoint;

request a report of an event summary from said endpoint;

performing an endpoint diagnostic check; and

requesting a report of memory content of said endpoint.

21. The AMR system of claim 14, wherein said command and control frame includes a plurality of fields, and wherein said plurality of fields are selected from: a frame ID field, a cell ID, a real-time clock field, a command flag field, a slot offset field, an unsolicited message field, an endpoint ID field, a security field, a command set field, a command body field, or a response frequency field.

22. The AMR system of claim 14, wherein said command and control frame designates a response frequency for said endpoint.

23. The AMR system of claim 14, wherein said command and control frame comprises a one-way programming frame or a two-way command and control frame.

24. The AMR system of claim 14, wherein said command and control frame provides a test command to said endpoint.

25. An automatic meter reading (AMR) system, comprising:

a plurality of readers

a plurality of endpoints, wherein each endpoint is interfaced to a utility meter, wherein said plurality of readers are capable of communicating with said plurality of endpoints via RF communication; and

wherein said plurality of readers are quasi-synchronized in time to provide a control frame to at least one of said plurality of endpoints.