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Embedded Sensor Node for Wireless Network and Control System using CMOS RF Transmitter For Telecom Applications

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Abstract: *Multi purpose wireless sensors node for wireless network and control system using CMOS QPSK RF transmitter is proposed. Embedded systems are often distributed and deployed in various environments. Wireless nodes attached to circuits or appliances sense the current and/or control the usage. Wireless sensor networks are application-specific, so they have to involve both software and hardware. The added contributions to this work is, portability of the system, compact, customizable according to the application needs, allow for higher degrees of security and data encryption, and allow for routing thus extending the coverage area. The system makes a good utilization of the BW using variable length frames. Proteus circuit simulation program is used with actual frame for the proposed bit frame generation. The presented system can be used in various fields including but not limited to: Irrigation and agricultural systems, Telecom applications for small range communication.ButSystem limitation is the number of sensors is limited in count. The bit rate is limited to 300Kbps according to the RF Module limitations. Max distance between the nodes is in the range of 20KM in (line of site) LOS and 1.5 to 2 KM in NLOS, thus limiting the max coverage area in high density areas and zones. The QPSK transmitter has been designed using UMC 130nm CMOS technology 1.2V supply, system simulation for data rate 10MBps. The transmitter has total power dissipation 1mW.The RF Module operating at Dual Frequency Band 902-928 MHz.*

Index: *Embedded system, RF module, WBAN, QPSK CMOS Transmitter, Packets-Bit Frames, sensors nodes and zones, Wireless sensor networks, Sensor systems, information processing, network design*

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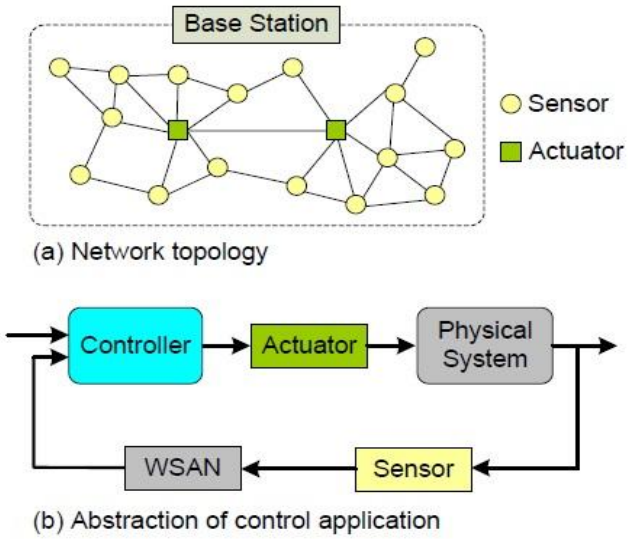
I. Introduction:

The Embedded wireless sensor and control network is actually a practical data logging, processing, encoding, recording, control wireless transmission system.It aims basically at sending data from various sensors and inputs located within the same physical area(node) to/from a remote station and receiving feedback or/and set-points for specific devices and control specific actuators based on the commands received.Data collected from each sensor, might be sent as it is or encoded using pre-defined encoding algorithms, stored in both node or in remote station according to user pre-defined configuration based in security concerns and system requirements.The node might encode the data collected from different sensors using one of many algorithms, sending the algorithm code no. and the decoding key within each frame.The central station(CS) might send the data to the nodes as it is or encoded using one of many algorithms, sending the algorithm code no. and the decoding key within each frame.The CS might enforce a specific node to encode its transmitted data due to some concerns related to security or reliability.The node can collect data of the following type: pressure, temperature, gas, speed, color, light intensity, vibration, direction, wind speed, altitude,GPS data and ON/OFF signal.This node can also control peripherals and devices using Controller Area Network CAN bus, IO port and dry contacts[1][2].The node may carry out some processing on values gathered by the sensor, to assure the values sent are accurate enough, and in format well known to the remote station, and also to maintain optimum, safe traffic, and send (save-our-soles)SOS signal to the remote station upon emergency or un-expected readings from the sensors, or sensor signal is lost or unrecoverable.The node may be configured either to connect only to specific CS or to any available CS or directly to the server using a GPRS modem.In our solution, the wireless connection is preferred, due to the ease of implementation.The use of advanced technology wireless modules like LORA, makes the wireless solution safe enough and reliable for almost all purposes[2][3].

II. WSAN for Control Applications

In general, there are three essential components in WSN: sensors, actuators, and base stations.The base stations are oftenresponsible for monitoring and managing the overall network through communications with sensorsand actuators. Depending on whether or not there are explicit controller entities within the network,two types of architectures of WSNs for control applications can be distinguished, as shown in Fig.1and Fig.2,

respectively. These two architectures are called automated architecture and semi-automatedarchitecture, respectively, in [1].In the first type of architecture as shown in Fig.1(a), there is no explicit controller entity in theWSAN. In this case, controllers are embedded into actuators and control algorithms for makingdecisions on what actions should be performed upon the physical systems will be executed on actuator nodes. The data gathered by sensors will be transmitted directly to the corresponding actuatorsvia single-hop or multi-hop communications. The actuators then process all incoming data byexecuting pre-designed control algorithms and perform appropriate actions. From the controlperspective, the actuator nodes serve as not only the actuators but also the controllers in control loops.From high-level view, wireless communications over WSNs are involved only in transmitting thesensed data from sensors to actuators; control commands do not need to experience any wirelesstransmission because the controllers and the actuators are logically integrated, as shown in Fig.1(b).



(a) Network topology,(b) Abstraction of control application

Fig. 1 WSAN Architecture without explicit controllers.

Fig.2(a) shows the second type of architecture, in which one or more controller entities explicitlyexist in WSN. The controller entities could be functional modules embedded in base stationsor separated nodes equipped with sufficient computation and communication capacities. With thisarchitecture, sensors send the collected data to the controller entities. The controller entities thenexecute certain control algorithms to produce control commands and send them to actuators. Finally,the actuators perform the actions. In this context, both the sensor data and control commands need tobe transmitted wirelessly in single-hop or multi-hop fashion. A high-level view of the applications ofthis architecture is depicted in Fig.2(b).

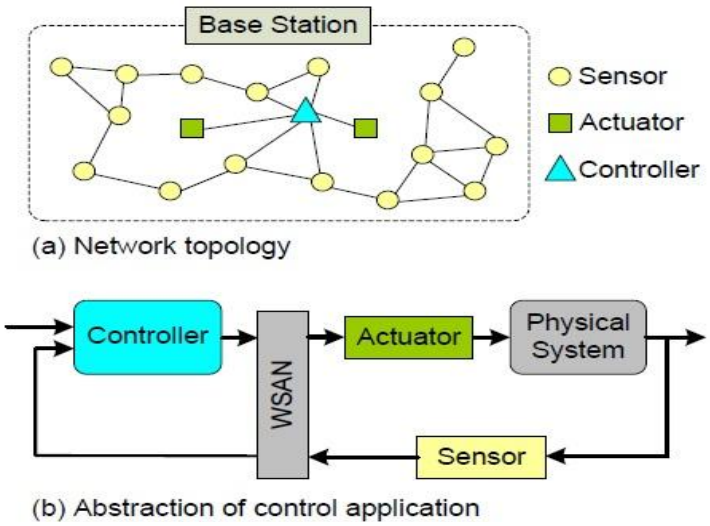


Fig.2. WSAN Architecture with explicit controllers.

In combination with the unique characteristics of WSNs, control applications pose the following main challenges associated with the design of WSNs:

• ***Reliability.*** From the control perspective, packet loss degrades control performance and evencauses system instability. Because practical control applications can only tolerate occasionalpacket losses with certain upper bound of allowable packet loss rate, WSN design shouldminimize the occurrence of packet losses as much as possible. Ideally, every packet should betransmitted successfully from the source to the destination without loss. However, due to manyfactors such as low-power radio communication, variable transmit power, multi-hoptransmission, noise, radio interference, and node mobility, packet loss cannot be completelyavoided in WSNs.

• ***Real-time constraint.*** Control systems are inherently real-time systems in the sense that controlactions must be performed on the physical systems by their deadlines. It is worth mentioningthat real-time does not necessarily mean 'fast'. For real-time control applications, both delayand its jitter should be limited and predictable in favor of control performance improvement.

III. System overview :

As shown in Fig.3, Sensor Node Block Diagram, the microcontroller will be the core of the system, collecting data from various sensors using different interfaces and protocols. The microcontroller will then act on each sensor according to its type and to the algorithms and encryption algorithms accompanied with this sensor if any, store some data in the flash memory, and form a frame to be sent to the wireless RF module. The node may also control some actuators directly through standard IO pins or DRY contacts , and may control smart devices using CAN bus. In case of high priority of this node or the need for this node to work independently without wireless network infrastructure, the node may be equipped with SIM900 GPRS allowing for direct connection to the central Server through the cloud. The formed frame will be sent to the RF module using the SPI protocol.

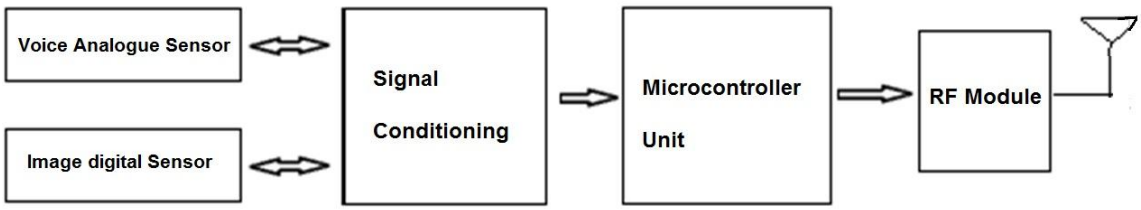


Fig. 3Sensor Node Block Diagram

IV. Generic Bit Frame Format :

Fig. 4 shows Generic frame format , where : No. of bytes in the frame: Indicates the total length of the frame in bytes, SRC node: the CS ID and node ID of the source node, DEST node: the CS ID and node ID of the destination node, Frame type: whether it is a sensor readings frame, or a confirmation to a command frame, or a command, Application type: Indicates whether frame is from medical, security system, Military, SCADA, Home automation, Industrial, agriculture, Telecom , No. of sensors in the frame: In case of frame type field is sensor reading, this field will indicate the number of the sensors readings in the frame , Priority level: The degree of importance of the frame for traffic priority , if this frame contains emergency message , or over threshold reading this field is set to high , Frame #: The number of the frame in the sequence, very important in case frame loss, or streaming audio or video , Encryption algorithm code: The algorithm used in the encoding of this frame 0 indicates none , Encryption algorithm key: The decoding key associated with the selected algorithm , Sensor no.: The sensor number whose data will be sent next to this byte , Sensor data length: Overall data length of the sensor or stream packet in case of streaming data into packets, this is the overall size of the packet , Sensor data length in the frame: amount of information sent from the sensor in this packet, used in case of streaming single packet over multiple frames, the max size of data from single sensor in frame is 100 , so if a sensor sends a 345 byte, the data of this sensor will be divided into 4 frames , 3 frames each contains 100 bytes and sensor data length in frame will be set to 100 , and the last frame will contain the last 45 bytes and the data length in the frame will be set to 45, the receiving node will then re-construct the packet using the frame number field and the sensor data length in the frame field along with the frame length field together , Sensor X data: The value of the sensor, if this is a streaming sensor (Audio , Video or data bigger than 100 byte) the data will be divided into blocks each 100 bytes and sent block by block with each frame then the receiver collects these blocks and re-form the original message , Sensor X type: The type of the sensor (temp , pressure, gas , ..Etc.), Sensor X key: Any specific factor or pre-scaler associated with the sensor reading , Response number : the response reference number in case of reply for certain frame or message , End of frame: A specific character

sent at the end of the frame, to act along with the no. of frames byte in the beginning of the frame in controlling the traffic , CRC: Cyclic Redundancy Check.

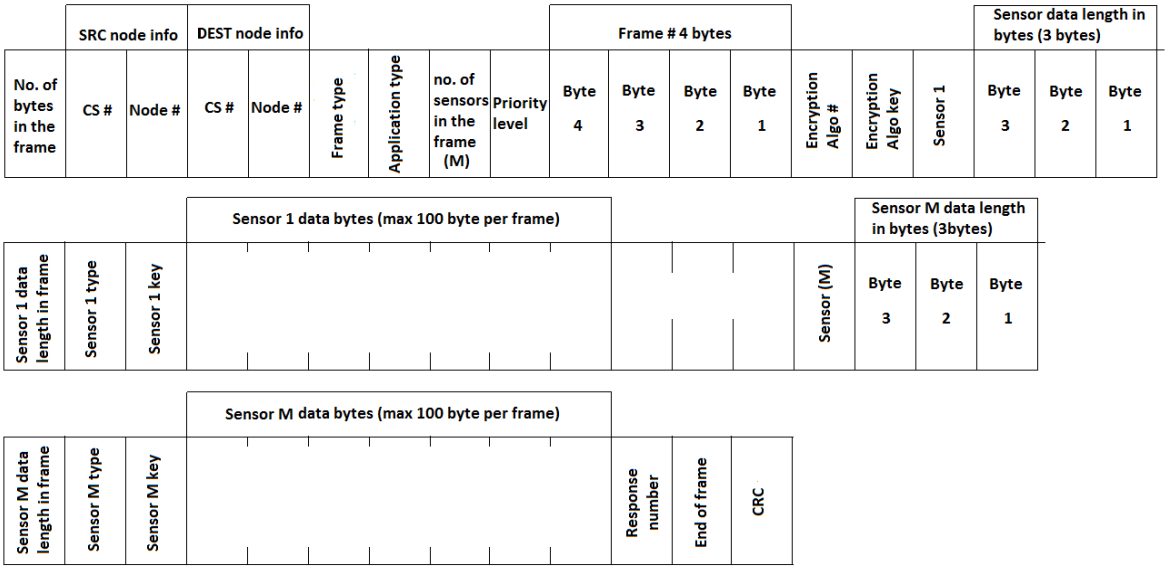


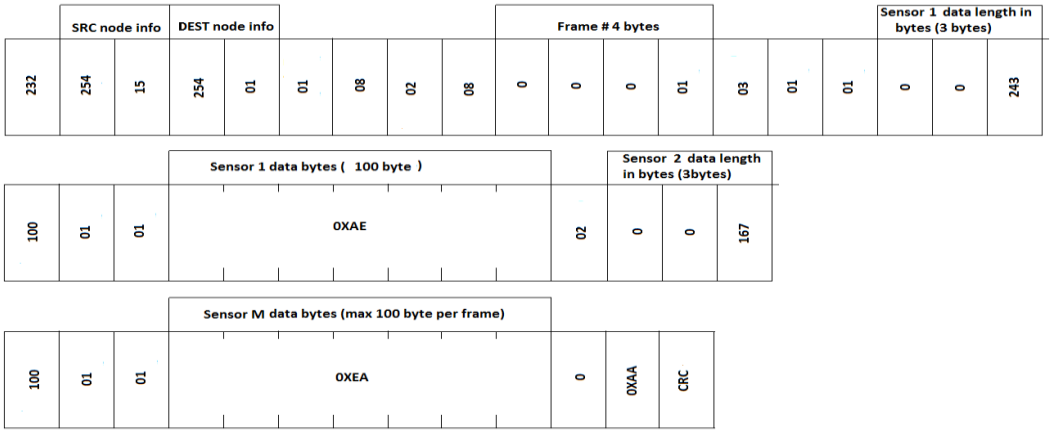
Fig. 4 Generic Bit Frame Format

V. Proposed Bit frame format for One single zone of Telecom applications :

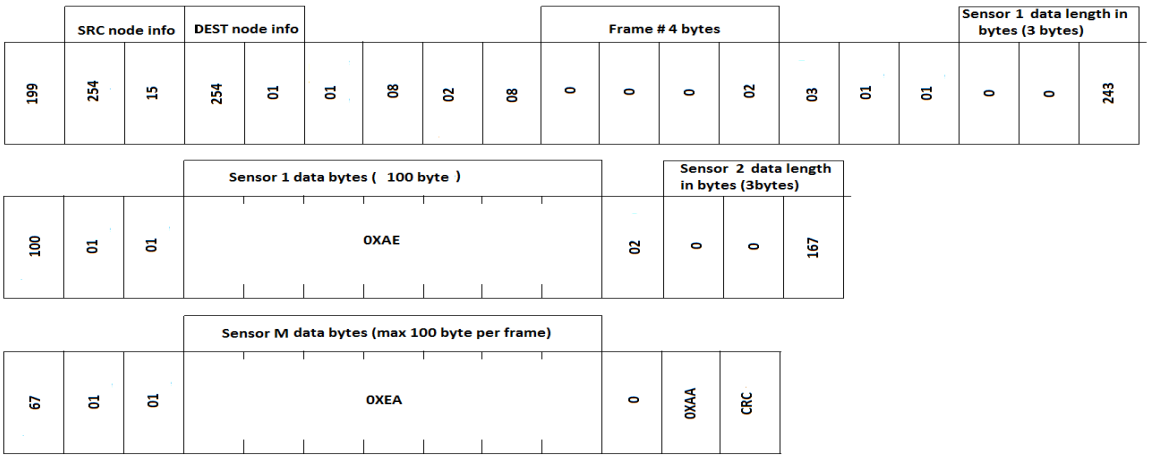
Frame sent from the node (ex. 15) this node contains 2 sensors, high priority to the CS

In this system configuration, the following parameters are set to pre-set values as shown in Fig.5:No. of bytes in the frame: Indicates the total length of the frame in bytes.SRC node: the CS ID and node ID of the source node, CS ID is set to 254 indicating Zone CS not external Zone, node ID 15 as indicated in the example.DEST node: the CS ID and node ID of the destination node, CS ID is set to 254 indicating Zone CS not external Zone, node ID set to 01, where the CS node is always 01, indicating master node.Frame type: set to 01 indicating sensors reading frame.Application type: set to 08 indicating telecom application.No. of sensors in the frame: set to 2 sensorsPriority level: set to 08 for high priority, where 01 priority is the least and 10 is emergency.Frame #: set to 00 and increments with the frame number.Encryption algorithm code: set to 03, first degree algorithmEncryption algorithm key: set to 01, for the sake of the example.Sensor no.: this number will change from 01 to 02.Sensor data length: set to **243 for sensor 1 and 167 for sensor 2.**Sensor data length in the frame: the frame will contain all the data of this sensor, this value changes from 100 to 43 after 2 frames for sensor 1 and changes to 67 after 1 frame for sensor 2. Sensor X data: for this example , the data will be (0XAE for sensor 1 and 0XEA for sensor 2).Sensor X type: sensor 1 type is 01 (for**Audio** in telecom app).sensor 2 type is 02 (for Audio in telecom app).Sensor X key: All keys will be set to 01, indicating no pre-scaler is assigned, use data as is.Response number: set to 00 as no need for a confirmation from the CS, if confirmation is needed a confirmation is assigned to this field and the CS must set this value to the response number assigned to the frame.End of frame: 0XAA.CRC: Cyclic redundancy check.Bit frame format for this case of Audio transfer for messages longer than 100 Bytes. Simulation results from Proteus circuit simulation program output of logic analyzer is shown in Fig.6.

Frame #1



Frame #2:



Frame #3:

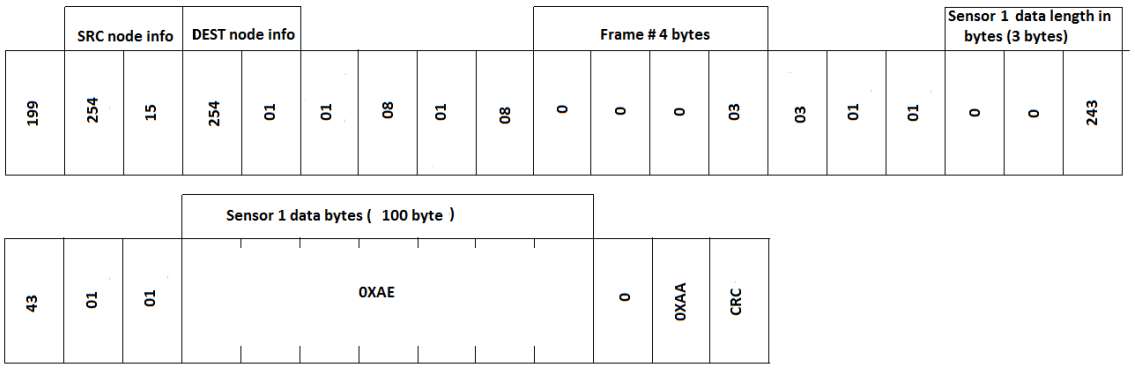


Fig. 5 Proposed Bit frame format for One single zone of Telecom applications

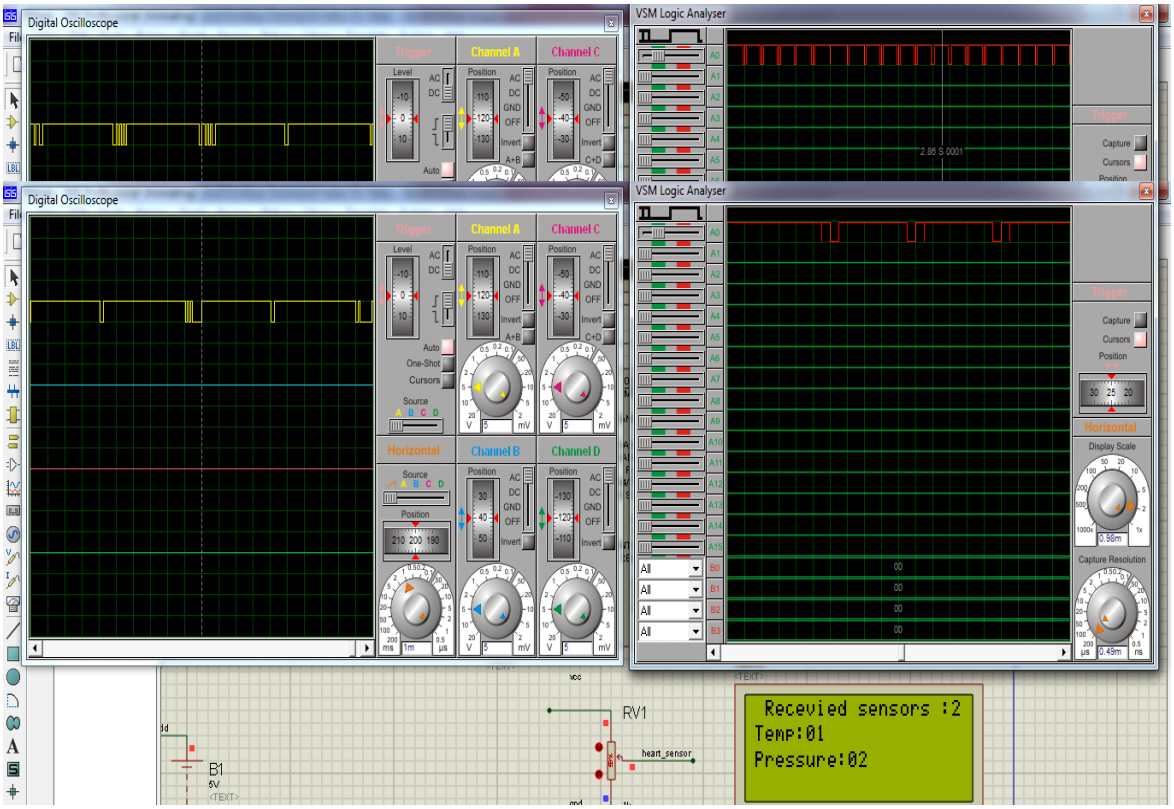
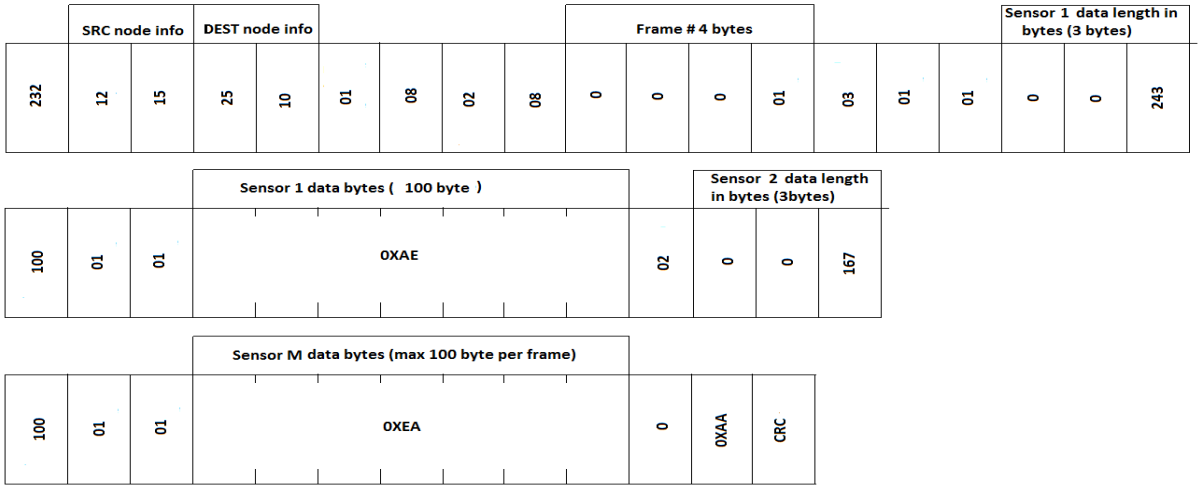


Fig. 6 Simulation results from Proteus circuit simulation programoutput of logic analyzer

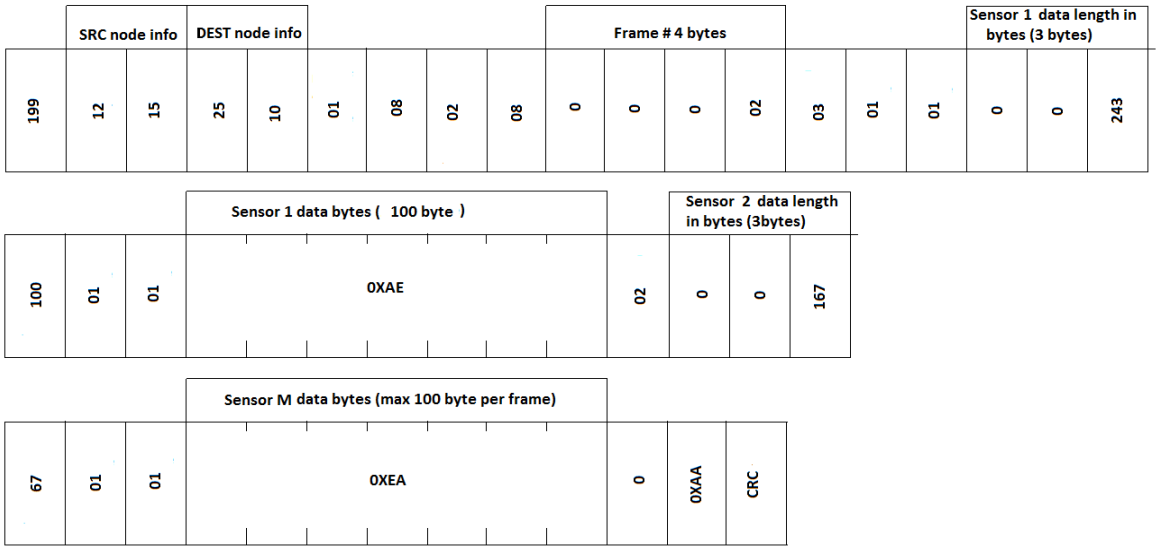
VI. Proposed Bit frame format forTwo different zones of Telecom applications :

Frame sent from the node (ex. 15) this node contains 2 sensors, high priority to the CS from another CS in different zone, the home CS is 12, the remote CS is 25, response is needed for this frame and given sequence 23. In this system configuration, the following parameters are set to pre-set values as shown in Fig.7 :No. of bytes in the frame: Indicates the total length of the frame in bytes.SRC node: the CS ID and node ID of the source node, CS ID is set to 12, node ID 15 as indicated in the example.DEST node: the CS ID and node ID of the destination node, CS ID is set to 25 indicating Zone CS not external Zone, node ID set to 10.Frame type: set to 01 indicating sensors reading frame.Application type: set to 08 indicating telecom application.No. of sensors in the frame: set to 2 sensorsPriority level: set to 08 for high priority, where 01 priority is the least and 10 is emergency.Frame #: set to 00 and increments with the frame number.Encryption algorithm code: set to 03, first degree algorithmEncryption algorithm key: set to 01, for the sake of the example.Sensor no.: this number will change from 01 to 02.Sensor data length: set to 243 for sensor 1 and 167 for sensor 2.Sensor data length in the frame: the frame will contain all the data of this sensor, this value changes from 100 to 43 after 2 frames for sensor 1 and changes to 67 after 1 frame for sensor 2, Sensor X data: for this example , the data will be (0XAE for sensor 1 and 0XEA for sensor 2).Sensor X type: sensor 1 type is 01 (for Audio in telecom app).sensor 2 type is 02 (for Audio in telecom app).Sensor X key: All keys will be set to 01, indicating no pre-scaler is assigned, use data as is.Response number: set to 00 as no need for a confirmation from the CS, if confirmation is needed a confirmation is assigned to this field and the CS must set this value to the response number assigned to the frame.End of frame: 0XAA.CRC: Cyclic redundancy check.Bit frame format for this case. Fig. 8 shows the result snap shot taken from Proteus circuit simulation program with actual frame for the proposed bit frame generation for Telecom application

Frame #1



Frame #2



Frame #3

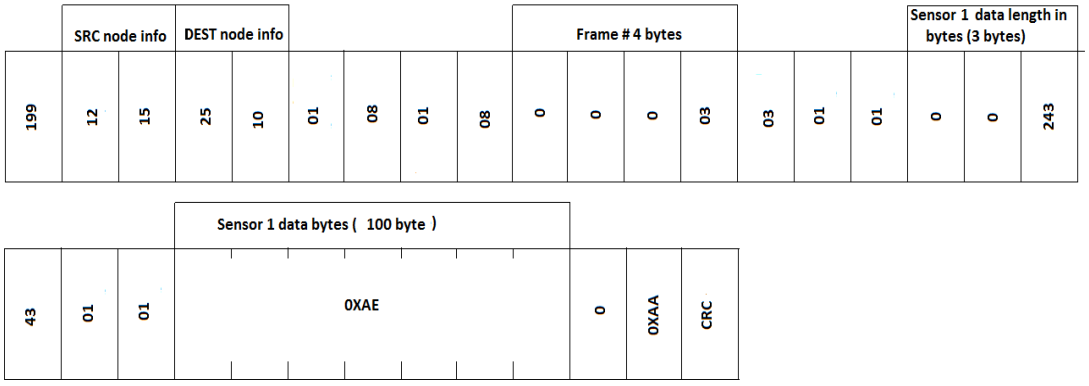


Fig. 7 Proposed Bit frame format for Two different zones of Telecom applications

VII. Simulation results from Proteus circuit simulation program output of logic analyzer

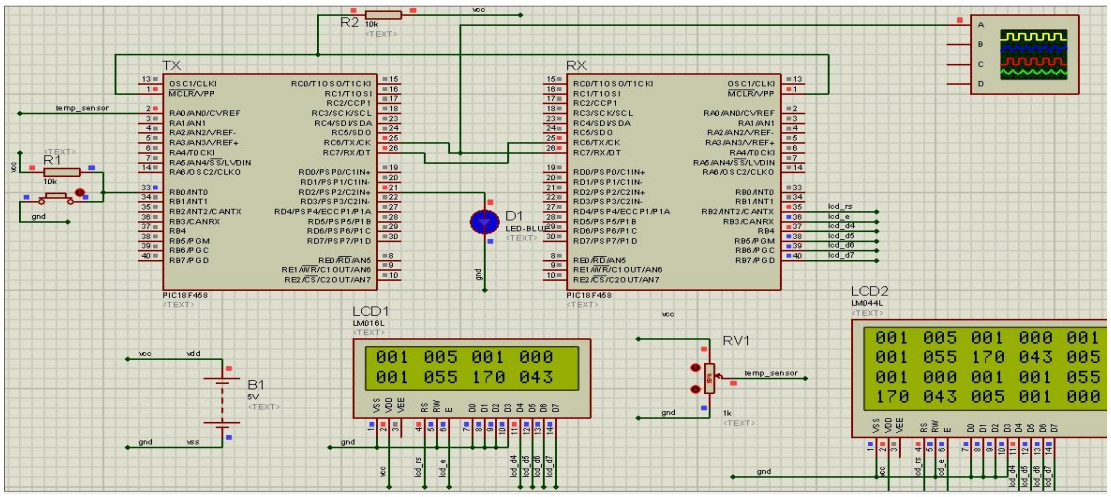


Fig. 8shows the result snap shot taken from Proteus circuit simulation program with actual frame for the proposed bit frame generation for Telecom application

VIII. System limitations and added Value :

The presented system has some limitations , that can be summarized in the following points:The number of sensors is limited in count.The bit rate is limited to 300Kbps as indicated by the manufacturer datasheet.Max distance between the nodes is in the range of 20KM in LOS and 1.5 to 2 KM in NLOS, thus limiting the max coverage area in high density areas and zones.The added contribution in this work is :The system is portable,compact,customizable according to application needs.The system allows for higher degrees of security and data encryption.The system allows for routing thus extending the coverage area.The system makes a good utilization of the BW by using variable length frames.

IX. RF Transmitter

QPSk RF transmitter is used to generate the RF signal to be transmitted. Fig.9 shows the block diagram of the proposed transmitter. The RF carrier (405 to 406 MHz) is generated by a ring oscillator (RO) while phase stability is obtained by a crystal oscillator 405MHz frequency range injected to the ring oscillator. The 10 channels are swept by a programmable charge pump that injects 10 different current levels to the RO, while the charge pump is controlled by a 10 bit control word B<0:9>. The outputs of RO (*f*oand) are input to four-quadrant phase shift block to generate four-quadrature RF carriers P0, P90, P180 and P270. The four carriers are then input to the Gilbert phase_MUX for QPSK data modulation. Finally the RF modulated signal is input to the power amplifier [4].

a. QPSK Mod.

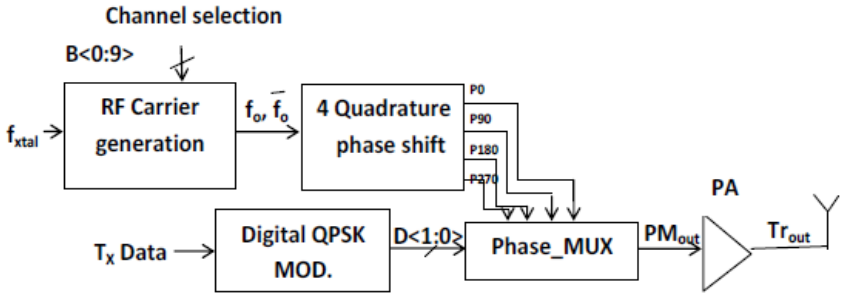


Fig.9 QPSK RF Transmitter

b. Power Amplifier

Nonlinear PA has been used due to its compatibility with the constant envelope of the QPSK signal, beside its high efficiency compared with other topologies. A zero current switching PA is designed [5] with two cascaded inverters. Fig.10 shows the circuit diagram of the PA with the first inverter - M1 and M2- acts as a buffer for the modulated signal output from the phase_MUX while the second inverter -M3 and M4- drives the matching network [5].

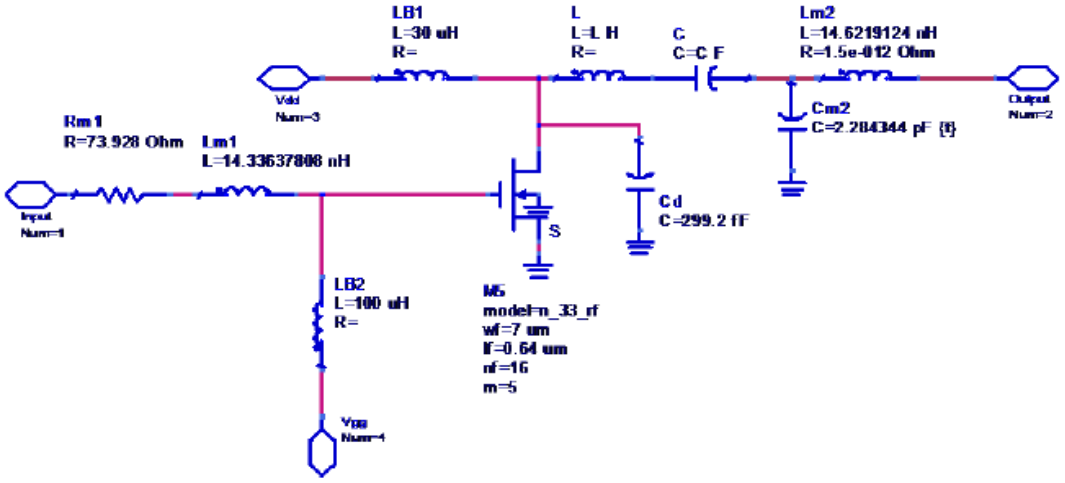


Fig.10 Power Amplifier

X. Simulation Result

The QPSK transmitter has been designed using UMC 130nm CMOS technology 1.2V supply, system simulation for data rate 10MBpsis shown in Fig.11. The transmitter has a total power dissipation of 1mW.

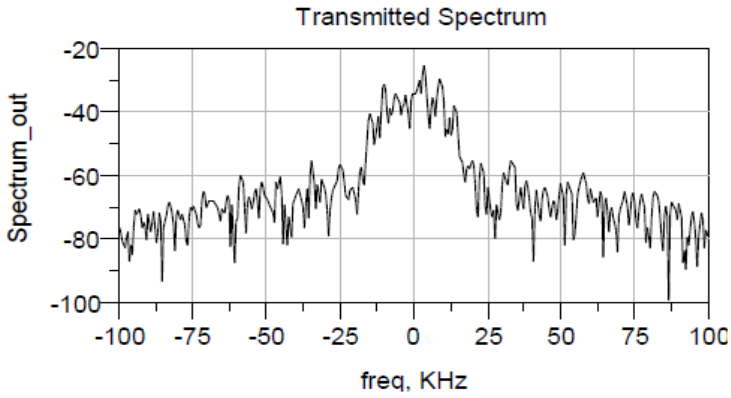


Fig.11 Complete system simulation

XI. Conclusion

The added contributions in this work are :Multi purpose wireless sensors nodes for wireless network and control system using Long Range RF Transmitter is proposed. Also, portability of the system and compact, customizable according to the application needs, allows for higher degrees of security and data encryption, and allow for routing thus extending the coverage area. The system makes a good utilization of the BW using variable length frames. Proteus circuit simulation program is used with actual frame for the proposed bit frame generation. The presented system can be used in various fields including but not limited to: Security systems, Military applications, Small scale SCADA system, Home automation, Industrial monitoring, Irrigation and agricultural systems, Telecom applications for small range communication. But **System limitations is** the number of sensors is limited in sensors count. The bit rate is limited to 300Kbps according to The LORA RF Module limitations. Max distance between the nodes is in the range of 20KM in (line of site) LOS and 1.5 to 2 KM in NLOS, thus limiting the max coverage area in high density areas and zones. The power amplifier is used to extend the range of the LORARF module. The QPSK transmitter has been designed using UMC 130nm CMOS technology 1.2V supply, system simulation was done for data rate 10MBps. The transmitter has the total power dissipation of 1mW.The RF Module operating at Dual Frequency Band 902-928 MHz.

Acknowledgment:

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