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CLUSTERING WIRELESS NODES BASED ON ADAPTIVE MODULATION WITH CUSTOMIZED KERNEL

[1]NAVANEETHAN.C, [2]HELEN PRABHA.K
[1]Research Scholar, Anna University, 600025, India
[2]Professor, R.M.D Engineering College, Tamil Nadu, 601 206, India
E-mail: [1]navaneethan_c@yahoo.com,[2] helenprabha@yahoo.com

ABSTRACT

In wireless network system, diversity techniques have been accepted as effective modes to conflict multipath fading due to delay or bandwidth constraints and explore the use of multiple transmit or receive antennas at the same terminal (spatial diversity). A cooperative diversity scheme avoids the size limitation by allowing the terminals to rely in parallel. In this work, we focus on wireless communication among nodes grouping them as different clusters so as to form a virtual logic channel for each cluster, implemented using kernel customized, low power consuming hardware modules. The proposed work enables a large number of simple low-power nodes to be distributed in a field and transmit data in a secured manner.

Keywords: *WSN, Modulation/Demodulation, node/network security, GNU, FL2440*

1. INTRODUCTION

Wireless sensor network (WSN) is one in which the duration of time after which a definite period of the battery-operated sensors exhausts their energy source and drop out of the network. The radio features for each sensor as well as the communication architecture of the WSN directly affects the system.

The WSN architectures have different applications with growing interest in hierarchical WSN to reduce the communication burden on the sensor nodes and hence, increase the system efficiency with longer period. Fixed relays with higher processing capability and higher energy level act as cluster-heads in order to collect events and measurements from a cluster of sensors and forward the data to a vital base station.

Although, there are significant research on energy efficient WSNs, less work has been done on the effects of physical layer and overall system design. Modulation scaling and adaptive modulation techniques are introduced, where the modulation level is adjusted to reduce the energy per bit. The modulation scaling is proposed where at lower data traffic, target bit error rate is altered to reduce the required energy per bit. The impact of using modulation scaling on packet delivery latency and packet loss is considered.

The adaptive modulation is used in a centralized cross-layer approach in order to minimize the total transmission energy consumption of the network. Every node group is adjusted to have a different bit rate according to its application. In these techniques, one common modulation scheme is considered depending on the channel conditions across the network to achieve lower required energy per bit.

1.1 Objective of the Work

The objectives of the work includes but not limited to

(i) Different modulation and demodulation switching ability for a node
(ii) Choosing a particular modulation so as to maintain an uniform SNR
(iii) Filtering the channel noise and automatically extracting the features and identifying the corresponding demodulator at receiver
(iv) Ensuring security if required by supporting existing encryption models without scalability issues.

The demonstrated modulation and demodulation schemes include,

a) ASK
b) D8PSK
c) CPFSK
d) QAM8
e) QASK

f) DQPSK
g) SUNDE
h) QAM 16
i) QAM 64
j) QAM 256

Typical wireless network includes,

(i) Nodes that allows a physical quantity to be measured,
(ii) Transmitter that allows data transfer between nodes,
(iii) Central Processing node allows the bitwise manipulation of the physical quantities measured and controls the communications protocol between nodes,
(iv) Power supply system.

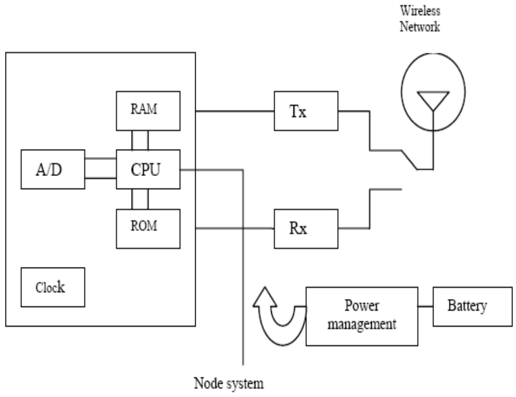


Figure 1. Diagram of connectivity between systems' Transmitter/Receiver in wireless network

2. PREVIOUS WORK

Rappaport, T. S.,discussed that energy dissipation due to data transmission is a major percentage of the overall energy consumption within the sensors. Laneman ,D . N. C. Tse, and G. W. Wornell, develops maximum likelihood detectors and the analysis for bit error rate . C. Schurgers, O. Aberthorne, and M. B. Srivastava, presented the concept of modulation scaling where at lower data traffic, target bit error rate is increased to reduce the required energy per bit.

V. Raghunathan, C. Schurgers, S. Park, and M. Srivastava proposed on energy-aware design in different layers of the network in order to extend the network lifetime. C. H. Liu and H. H. Asada proposed to allocate time or frequency channels, to improved efficiecy in sensor networks. Laneman , . N. C. Tse, and G. W. Wornell presented cooperative diversity that does not increase the maximum sum-rate comparing with noncooperative transmission which is unavailable to the transmitters but available to the receivers.

Z. Yang, Y. Yuan, J. He, and W. Chen proposed the impact of using modulation scaling on packet delivery latency and packet loss is considered. Longbi, , Ness B. Shroff, and R. Srikant, presented a model to characterize the performance of multihop radio networks in the presence of energy constraints and design routing algorithms to optimally utilize the available energy. A.Iranli , M.Maleki and M.Pedrum presented a model in WSN to reduce the distance by different routing and assignment techniques.

D.B.Faria and D.R.Cheriton proposed wireless access points function as network sensors Deqiang Chen, and J. Nicholas Laneman developed a general framework for maximum likelihood (ML) demodulation in cooperative wireless communication systems. Z. Li, W. Xu, R. Miller and W. Trappe proposed to identify and characterize relationships between pairs of wireless transceivers. It can determine communications sent by the same user, requires prior authentication in order to verify the identity of a communicant. M. Soltan, M. Maleki, and M. Pedram presented various WSN architectures proposed for different applications. It reduces the communication burden on the sensor nodes and hence increases the system efficiency. V. Brik, S. Banerjee, M. Gruteser, and S. Oh presented a classifying frames based on features extracted from the modulation domain. Maryam Soltan, Inkwon Hwang, Massoud Pedram, presented wireless sensor networks (WSN) with hierarchical organizations attracted a lot of attention as effective platforms for pervasive computing. B. Danev and S. Capkun proposed a transient-based approach in identifying nodes in a sensor network.

Zhou, Y., Pan, Z presented for filter requirements and to reduce the noise. ,W., Yue, Y., Zhou, T presented on the monolithic integration with radio and digital circuitry such as digital baseband physical layer (PHY), media access control (MAC) functions and microcontroller. Zhang, C., Wei, C., Jiang, H., Wang, Z proposed the development of fully integrated sensor SoC with radio transceiver targeted towards wireless sensor networks in 2.4-GHz ISM-band and a sensor signal processor. Dong-Sun Kim, Sung-Joon Jang and Tae-Ho Hwang presented a single-chip sensor using system-on-a-chip (SoC) that implements cognitive radio at 2.4 GHz complete digital baseband physical layer (PHY), 10-bit sigma-delta, analog-to-digital converter and dedicated sensor calibration hardware for industrial sensing systems.

3. COMMUNICATION PROCESS AMONG NODES

The node to node communication need to use power saving mechanisms and explore good routing algorithms to cover wide WSNs. The OSI levels, i.e. Physical layer and network layer are used in this work.

3.1 Physical Layer

This layer modulates and demodulates the transmitted signal. This layer realizes a robust modulation scheme with as small an overhead as possible. Different modulation schemes are adopted and the nodes packets includes,

(i) Preamble, useful for timing the nodes and identifying the type of data,

(ii) The user information and error detection and correction scheme to detect and correct errors (otherwise error packet is discarded and retransmission request is sent thereby resulting in loss of power).

4. NODE SYSTEM ANALYSIS AND APPROACH

In this approach, among the different modulation schemes, for a specified E_b/N_0 ratio, where E_b is needed energy per bit at the receiver in order to satisfy a maximum bit error rate (BER) and N_0 ratio of the energy per bit to the noise power spectral density. The selection of the modulation scheme at various sensors nodes is done. The proper choice of the modulation schemes at various nodes, ensure reduction of the average power consumption and the network power distribution over the coverage area. Event aggregator relay (EAR) nodes are assumed to support multiple modulation schemes either via multiple receivers or via a single software-defined configurable receiver. The modulation selection algorithm used in this work is as follow,

(i) For the nodes which are closer to the *EAR* node, select a lesser complex modulation scheme that requires larger E_b/N_0.

(ii) For those nodes farther away, Modulation can be a more complex modulation scheme such that same BER can be achieved with smaller E_b/N_0.

4.1 Variable Packet Size Effects

Consider the node to node data transfer using datagram approach. The effect of having a dynamic packet size for N hops is discussed in this section. Typically,

Packet size= Data length + Header
If data length L= M bytes and Header bytes=H,
Total packet size=M+H bytes.

Case (i)

Let, packet size P=M+H. Then with a byte transfer time of 'T' units, total time to transmit from source node to destination node through N hops is

T_d= (M+H) N T

The time-scheduler diagram for the single packet case is shown in figure 2. The same for variable data size packets (two i.e. P1, P2) is shown in figure 3.

Case (ii)

Let, packet size be M/2 and with total of two packets each of equal size i.e.

M/2 bytes+ H Header bytes = size of P_1 = size of P_2

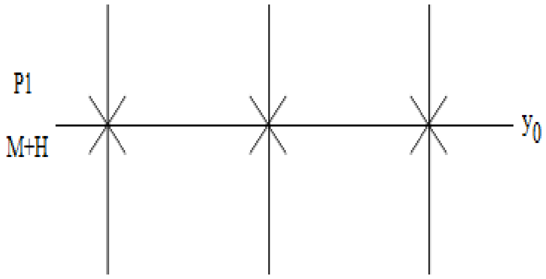


Figure 2. Time-Packet Scheduler diagram

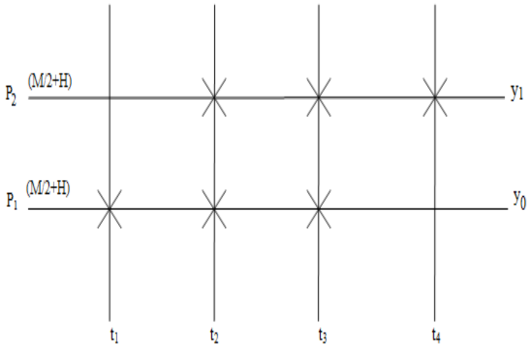


Figure 3. Time-packet scheduler for variable data size packets

Table 1.Node Transmission in Time Packet Scheduler

Time	Node Transmission	No. of bytes transmitted during the time period	No. of seconds needed
t_1	1 → 2	M/2+H bytes of P_1	(M/2+H)T
t_2	2 →3	(M/2+H)bytes of P_1	(M/2+H)T
	1 →2	(M/2+H) bytes of P_2	
t_3	3→ 4	(M/2+H) bytes	(M/2+H

		of P_1	)T
	2→ 3	(M/2+H) bytes of P_2	
t_4	3→ 4	(M/2+H) bytes of P_2	(M/2+H)T

5. COMMUNICATION MODEL

The communication model consists of the transmitter (figure 4) and the receiver (figure 5).

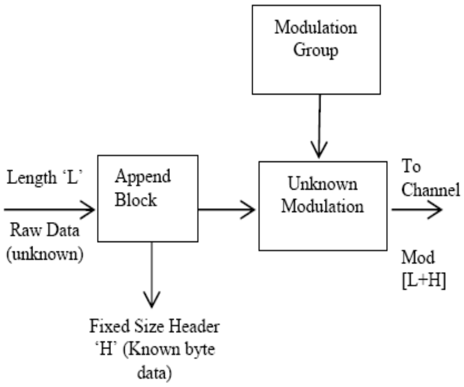


Figure 4. Transmitter

Synchronization Procedure

At Tx:

S1: $Packet_1$

Size of Mod [L+H]

S2: $Packet_2$ to $Packet_N$

Mod [L+H]

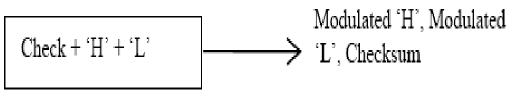
At Rx:

S1: Receiver

Size of Mod [L+H] i.e. S1: $Packet_1$

S2: Identify end of packets by using S1: i.e. after each fixed size, increment a counter and check whether size of Mod [L+H] is reached.

Connection Scheme



The checksum is the size of the [Modulated data + 4-byte Modulated Header]. This helps in establishing a non-connection oriented UDP layer module with an intrinsic error handling capability using checksum. However, specific packet error detection cannot be carried out, and such a requirement can be satisfied using error detection modules like CRC (or) error correction modules like Hamming code.

Specifications

Chosen 'H' = 0XAA 0X55 0XAA 0X55

Available Modulation type: Ten Modes used for testing

Type of Noise added: Gaussian with channel fading effects

Type of data using for testing: Image file of variable size

Maximum Modulation date size for BASK: 200 KB

Minimum Modulation date size for QAM256: 17KB

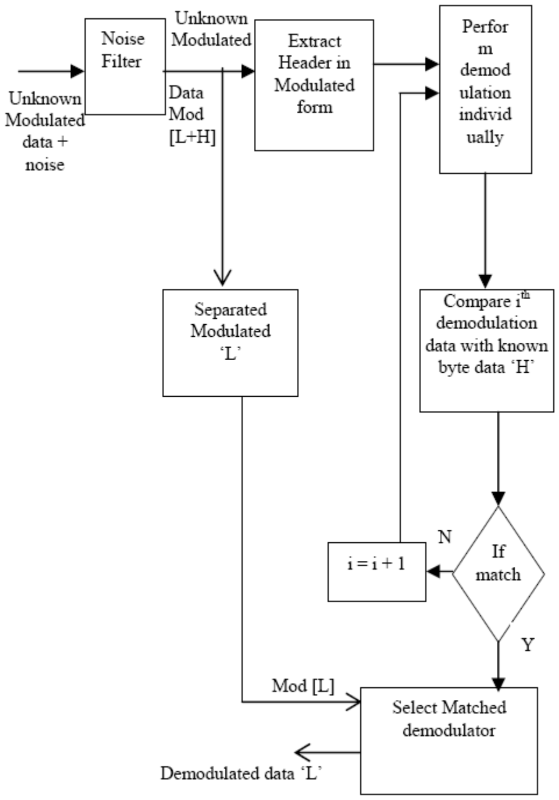
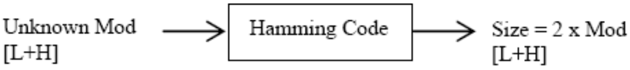


Figure 5. Receiver

Optional

Encoder and Decoder to build self-healing property to data



The Hamming code interleaves a 3 Bit check code into a nibble and virtually converts a nibble into a byte. Hence, Size of encoded data is 2xMod [L+H].

At RX:

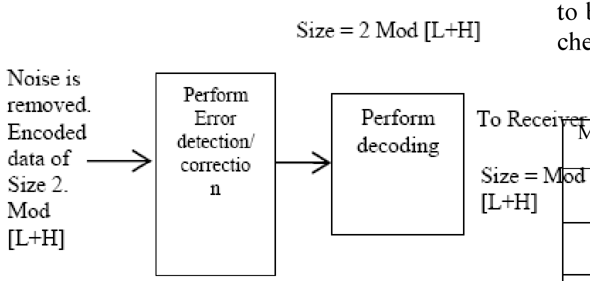


Figure 6. Error Detection and correction at Rx

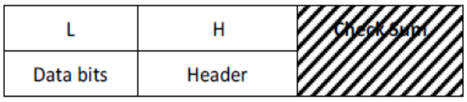
Thus, an optional self-healing layer can be introduced, however, with a trade-off of increase in data size.

Table 2. Comparison Of UDP/ TCP With Respect to Data Size

Comparison	Data Size	Check sum	Error indication	Error corrector
Non-Connection Oriented (Ex: UDP)	Mod [L+H]	✓	✓	×
Encoded Non-Connection oriented	2xMod [L+H]	✓	✓	✓
Connection oriented (Ex: TCP)	Mod [L+H]	×	in the form of packet Timeout	× only retransmit

Case (i)

Data Format



Initial Stage

After Modulation

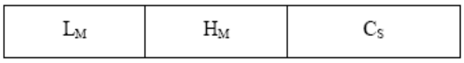


Figure 7. Header Format before and after Modulation

Where L_M+H_M=Modulation [L+H],

C_S ➔denoting the size of (L_M+H_M)

Ex : -

For L=2KB; H=4bytes and with the Chosen Modulation,

If L_M = 200 KB; H_M = 400 bytes,

Then C_S will be of size 18 bits, such that with 18 bits check sum, up to file size of 256KB can be transmitted (i.e. 2^{18} = 256KB). If large size data is to be modulated, then number of bits for indicating checksum and time of data transfer will increase.

Table3l.Calculating Checksum Based On Bits

Modulated data size i.e. size (L_M+H_M)	Number of check sum bits i.e. C_S	
≤ 1KB	10 bits	i.e. 2^{CS}
≤ 64KB	16 bits	
≤ 1MB	20 bits	
≤ 1GB	30 bits	

6. ENERGY AWARE ROUTING AMONG NODES

Energy-aware routing selects the energy-efficient route to forward the packets, at the cost of computational overhead among the nodes in the network. With the support of energy aware among the network nodes, incremental deployment of nodes is almost mandatory. Even for networks with nodal energy replenishment, the failure of the electronic devices at nodes, as well as the potentially unpredictable number of monitored events, makes it desirable to have the ability to deploy nodes in an incremental approach [8].

6.1. Case (i) Node to Node Communication with Inherited Circuit Switching

Let T= $\sum_{i=1}^{M} C_i$

Where, $C_1 =$ call setup time;

$C_2 =$ Message Delivery time

If ‘D’ is the propagation delay

‘L’ is the data size

‘B’ is the baud rate

‘N’ is the no. of hops between two end stations

Then,

$$C_2 - ND + \frac{L}{B}$$

$$\therefore T = C_1 + ND + \frac{L}{B}$$

6.2 Case (ii) Node to Node Communication with Inherited Datagram Switching

T=$\sum_{i=1}^{N} T_i$

Where, N is the number of hops and T_i is the time to transmit and deliver all packets through ith hop.

Specifically, $T_i = N_p\tau + l$

Where, N_p is number of packets, $'\tau'$ is the transmission time for one packet and

$$\tau = \frac{packet\ size}{baud\ rate} = \frac{P}{B}$$

$$T_1 = N_p\frac{P}{B} + D$$

T_2 to T_N satisfy the condition

$$T_2 = T_3 = \dots = T_N = \tau + D = \frac{P}{B} + D$$

$$\therefore\ T = T_1 + \Sigma_{i=2}^{N} T_i = N_p + \frac{P}{B} + D + \left(\frac{P}{B} + D\right)(N-1)$$

In general,

$$T = (N_p + N - 1)\frac{P}{B} + ND \qquad (1)$$

6.3 Case (iii) Node to Node Communication with Virtual Circuit Packet Switching

T= Time for setup +Time for case (ii)

$$= C_1(N_p + N - 1)\frac{P}{B} + ND$$

6.4 Maximizing Efficiency

The result for case (ii) is presented in this section.

From eqn. (1) $T = (N_p + N - 1)\frac{P}{B} + ND$

The number of packets N_P is optimized = $\left\lceil \frac{L}{(P-H)} \right\rceil$

where, $\lceil x \rceil$ is the nearest integer exceeding 'x'
Neglecting propagation delay i.e. if 'D'=0; then

$$T = \left(\frac{L}{P-H} + N - 1\right)\frac{P}{B}$$

In the above eqn. packet size 'P' is variable and for minimal 'T'

$$\therefore \frac{dT}{dp} = 0 \text{ gives}$$

$$P = H + \sqrt{\frac{LH}{N-1}} \qquad (2)$$

To minimize 'T' the following approaches have been identified,

(i) Reducing 'L' by using suitable lossless compression schemes. This involves selecting a suitable modulation that can achieve reduced 'L' without data loss.

(ii) Reducing 'H' by wherever possible by embedding virtual logical channels so that the route taken by a node is fixed and 'H' need not contain route information i.e. node clustering

(iii) Increasing 'N' by introducing optimal buffers such that overhead due to excess buffers does not affect the overall performance much.

7. EFFECT OF MODULATION ON DATA SIZE

In this work, for a given data size, the modulated data size for the ten different modulation schemes is studied. For example: for a 3kb data size, the modulated data size is tabulated in Table IV.

Table 4. Data size Vs Modulation Size = 3.1KB

Modulation Type	Modulation data size (L in bytes)
ASK	205568
D8PSK	68554
CPFSK	205568
QAM 8	68544
QASK	102784
DQPSK	102784
SUNDE	205568
QAM16	51408
QAM 64	34272
QAM256	25704

Table 5.Noise Level Tolerated VsModulation

Modulation Type	Tolerated noise level
ASK	0.1
D8PSK	0.06
CPFSK	0.07
QAM 8	0.08
QASK	0.2
DQPSK	0.1
SUNDE	0.1
QAM16	0.09
QAM 64	0.03
QAM256	0.01

Table IV helps to achieve lesser end-end transmission delay. Table V helps to achieve long distance single hop transmission of packets.

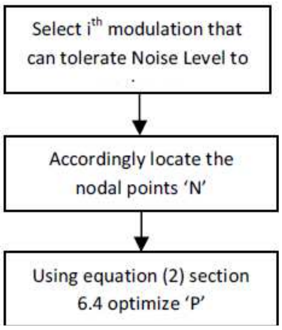


Figure 8. Inference from Table-IV

8. MODULATION DETECTION

In this work, Automatic modulation detection extracts multiple parameters (Features based on amplitude, frequency and phase) for identification of different modulation techniques namely: ASK2, ASK4, FSK2, FSK4, PSK2, PSK4, QAM16 and QAM64. The thresholds for different parameters have been calculated for the classification during training in real time situation. The parameters are carefully chosen based on signal statistics. The parameters selected are,

1. Absenv

$$absEnv = \frac{1}{N}\sum_{i=1}^{N}|A_{cm}[i]| \qquad (3)$$

2. AbsPhase

$$absPhase = \frac{1}{c}\sum_{A_n[i]>a_i}|\varnothing_c[i]|$$

$$\varnothing_c[i] = \varnothing[i] - \frac{1}{N}\sum_{j=1}^{N}\varnothing[j] \qquad (4)$$

3. rEnv

$$rEnv = \frac{1}{N}\sum_{i=1}^{N}|A[i] - m_a|/m_a \qquad (5)$$

4. absEnv2

$$rEnv2 = \frac{1}{N}\sum_{i=1}^{N}|B_{cn}[i] - m_b|$$

$$B_{cn}[i] = |A_{cn}[i]|$$

$$m_b = \frac{1}{N}\sum_{i=1}^{N}B_{cn}[i] \qquad (6)$$

5. absFreq

$$absFreq = \frac{1}{c}\sum_{A_n[i]>a_i}\left|\frac{f[i] - f_A}{F_{sym}}\right|$$

$$f_a = \frac{1}{c}\sum_{A_n[i]>a_i}f[i] \qquad (7)$$

6. absFreq2

$$absFreq2 = \frac{1}{c}\sum_{A_n[i]>a_i}\left|f_2[i] - \frac{1}{c}\sum_{A_n[j]>a_i}f_2[j]\right|$$

$$f_2[i] = \left|\frac{f[i] - f_a}{F_{sym}}\right| \qquad (8)$$

7. absPhase2

$$absPhase2 = \frac{1}{c}\sum_{A_n[i]>a_i}\left|\varnothing_2[i] - \frac{1}{c}\sum_{A_n[j]>a_i}\varnothing_2[j]\right|$$

$$\varnothing_2[i] = |\varnothing_c[i]| \qquad (9)$$

The method of classification as mentioned above is based on the threshold value and is calculated for various modulation techniques. Based on the flow chart shown in figure 9 the type of modulation transmitted to the receiver is identified.

9. HARDWARE IMPLEMENTATION

The implementation uses two hardware nodes (ARM 9 and above based architecture with "gnu radio" LINUX drivers installed)

(i) Transmitter board consisting of all the modulation blocks
(ii) Receiver board consisting of all the demodulation blocks

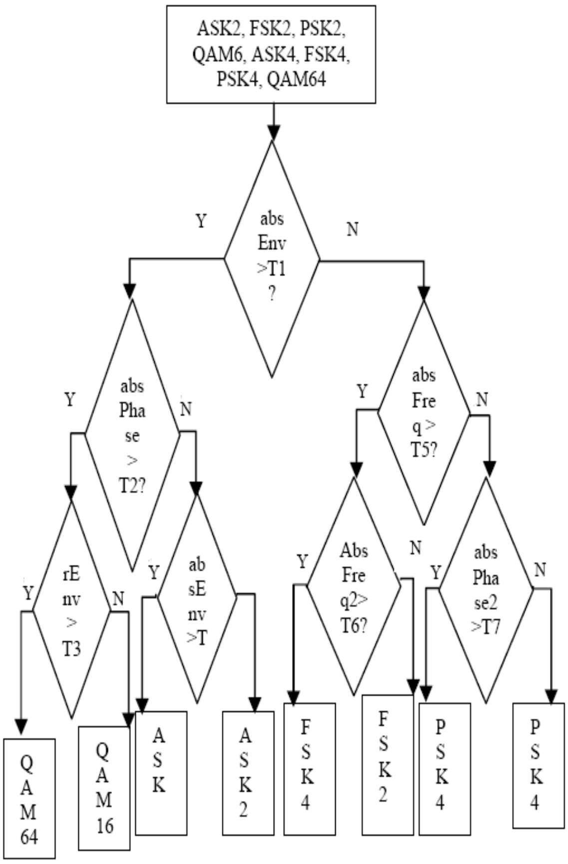


Figure 9. Modulation identifier Algorithm

Transmitter Block

The transmitter board consists of carrier generator, various modulation blocks, modulation selection switch, noise generator, DAC converter as shown in figure 10. Any one of the modulation core is selected using the "modulation selection switch" and the appropriate software block is activated. The Carrier is generated using the carrier generation core. The variance of the noise is selectable and is generated using the noise generation core. The modulated wave is transmitted as an analog signal using on board DAC.

9.2 Receiver Block

The receiver board consists of carrier generator, various demodulation blocks, noise generator and ADC converter as shown in Figure 11. The modulated signal is sampled through Analog to Digital converter at a high sampling rate. The digitized signal is then noise filtered by the noise filtering block. The modulation scheme is detected as discussed in section V on the sampled data. Based on the detected modulation scheme, appropriate demodulation core is activated and data is demodulated.

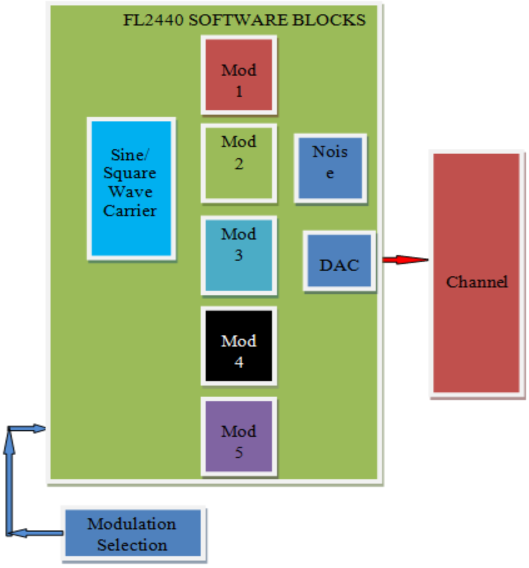


Figure 10. Transmitter board consisting of all the modulation blocks

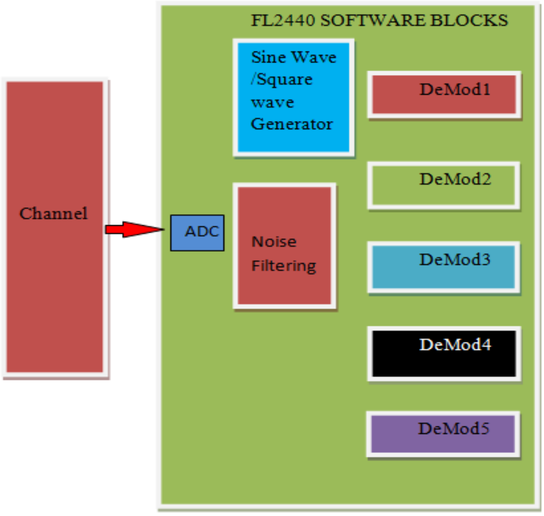


Figure 11. Receiver board consisting of all the demodulation blocks

Figure 12. Hardware Implementation

Case (i) 16 QAM Implementation details

16QAM, commonly used in radio networks and microwave digital radios, offers four values for ‘I’ and four values for ‘Q’, yielding 16 possible states, as shown in Figure 13. 16QAM sends four bits per symbol. The signal can transition from any state to any other state. 16QAM is more spectrally efficient than BPSK, QPSK, OQPSK, and π/4- DQPSK. This approach suffers from increased problems with inter-symbol interference due to the nonlinearity of the transmitter and receiver paths along with noise may cause one symbol to be interpreted as another symbol, thus, causing an error.

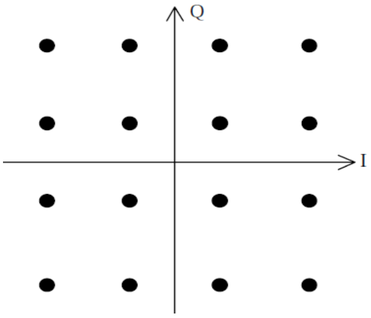


Figure 13. 16QAM State Diagram

The 16QAM implementation, shows a flow chart in which it import the GNU radio blocks, select the defaults values (provided by GNU blocks) and provide the modulation/demodulation for 16 QAM process (refer figure 14).

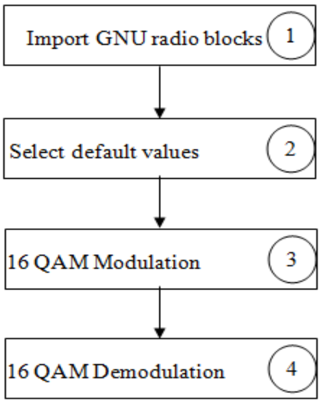


Figure 14. 16QAM implementation block

Case (ii) PSK Implementation

Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing or modulating, the phase of a reference signal (the carrier wave). Any digital modulation scheme uses a finite number of distinct signals to represent digital data. PSK uses finite number of phases, each assigned a unique pattern of binary digits. Usually, each phase encodes an equal number of bits. Each pattern of bits forms the symbol that is represented by the particular phase. DPSK can be significantly simpler to implement than ordinary PSK since, there is no need for the demodulator to have a copy of the reference signal to determine the exact phase of the received signal. In Figure 15 imported GNU blocks generate gray code constellation for different M-PSK values, convert the code and receive demodulation for PSK.

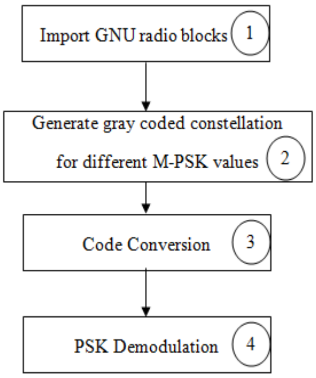
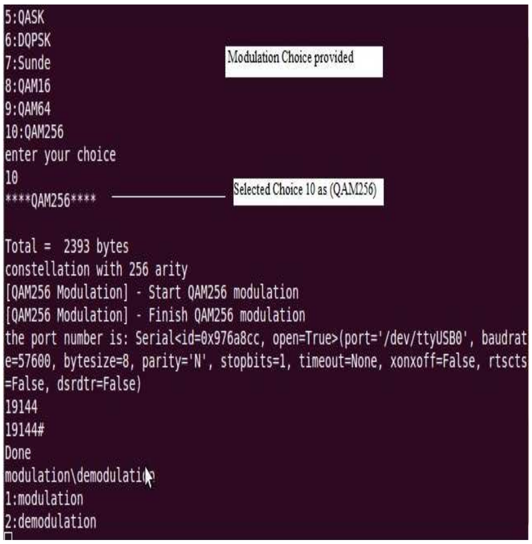


Figure 15. PSK implementation block

10. RESULTS AND DISCUSSION

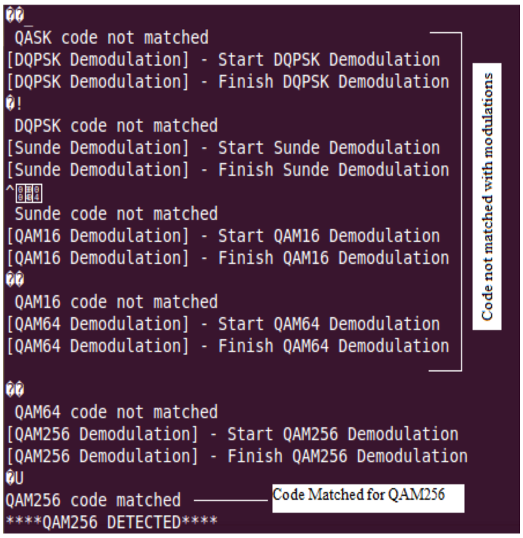
In this work, the experimental results have been obtained on linux hardware where different choices for modulation exist. Figure 16 shows the constellation with 256 parity along with the start and end status of the modulation and the status of port number. The automatically detected QAM output is shown in figure 17.



```
5:QASK
6:DQPSK
7:Sunde
8:QAM16
9:QAM64
10:QAM256
enter your choice
10
****QAM256****

Total =  2393 bytes
constellation with 256 arity
[QAM256 Modulation] - Start QAM256 modulation
[QAM256 Modulation] - Finish QAM256 modulation
the port number is: Serial<id=0x976a8cc, open=True>(port='/dev/ttyUSB0', baudrat
e=57600, bytesize=8, parity='N', stopbits=1, timeout=None, xonxoff=False, rtscts
=False, dsrdtr=False)
19144
19144#
Done
modulation\demodulation
1:modulation
2:demodulation
```

Figure 16. QAM256 Modulation/demodulation process



```
��_
 QASK code not matched
[DQPSK Demodulation] - Start DQPSK Demodulation
[DQPSK Demodulation] - Finish DQPSK Demodulation
�!
 DQPSK code not matched
[Sunde Demodulation] - Start Sunde Demodulation
[Sunde Demodulation] - Finish Sunde Demodulation
^�
 Sunde code not matched
[QAM16 Demodulation] - Start QAM16 Demodulation
[QAM16 Demodulation] - Finish QAM16 Demodulation
��
 QAM16 code not matched
[QAM64 Demodulation] - Start QAM64 Demodulation
[QAM64 Demodulation] - Finish QAM64 Demodulation

��
 QAM64 code not matched
[QAM256 Demodulation] - Start QAM256 Demodulation
[QAM256 Demodulation] - Finish QAM256 Demodulation
�U
QAM256 code matched
****QAM256 DETECTED****
```

Figure 17. QAM detection output

11. CONCLUSION

In this work, by selecting a suitable modulation, data loss is minimized and node clustering with reduced end to end transmission delay (to support long distance single/multiple hop transmission of packets) is achieved. The use of GNUradio cores makes the scheme scalable and easily implementable in standalone nodes powered with linux kernel. The metrics studied include packet size, end-end delay and optimizing the header bytes. Implementation results with real-time hardware are also done on FL2440 board for different types of commonly used modulation schemes. Future direction of study shall focus on placing the module with different nodes in the network layer and including the channel conditions for optimization the type of modulation chosen dynamically so as to improve the network coverage.

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