RELIABLE MULTI PATH ROUTING FOR 802.16 WIRELESS MESH NETWORKS

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Abstract

The effective technique to avoid congestion and losses in networks is by multipath routing. Multipath routing constructs multiple paths for a source and destination and provides fault-tolerance and reliability. In IEEE 802.16 Wireless Mesh Networks (WMN), very little work has been done on multipath routing. Also traditional multipath routing protocols induce the flooding of control messages and congestion in gateways. In this paper, we propose a Reliable multipath routing (RMR) protocol for 802.16 wireless mesh networks. It consists of a combined routing metric which is based on interference and load on the links. Multiple shortest paths are discovered based on the combined routing metric and the source node chooses the path with the minimum weight value as the primary path. The paths with next minimum weight values are selected as backup paths. Initially the data transmission takes place using the primary path and during any fault, it can be switched over the backup paths. By simulation results, we show that the proposed protocol provides better throughput with reduced delay and overhead.

Keywords: Wireless Mesh Networks (WMN), IEEE 802.16, Multipath Routing Protocol, Quality of Service (QoS), backup paths.

1. Introduction

1.1 Wireless Mesh Networks

The feasible solution to understand broadband wireless internet access in a flexible and economic way is with the help of wireless mesh networks. This is because it posses easy installation facility and faster expendability with inclusion of new mesh nodes. Hence, WMNs can be utilized to widen the cell ranges, cover shadowed areas, and to improve the system throughput. There is a need for quality of service (QoS) support in these networks in order to support voice, video and data services. These needs can be accomplished by means of mesh mode in IEEE 802.16. IEEE 802.16 defines both physical and MAC layer similar to other IEEE standards. The orthogonal frequency division multiplexing (OFDM) which is utilized in the mesh mode is defined for the frequencies among 2 and 11 GHz and the time division multiple access (TDMA) is used for MAC layer for maintain multiple users. [1]

IEEE 802.16 is economic and gives high data rates and high quality radio coverage and also it maintains improved QoS for high data rate applications. The application includes disaster recovery networks and backbone solutions over difficult terrain such as mountain areas. [2]

IEEE 802.16 has two modes by which the wireless medium is shared.

1) **Point to point (PMP):** In this mode, the network association processes are done by the base station (BS) which has to manage subscriber stations (SSs).
2) **Mesh mode**: In this mode, SS can interact with each other directly. This is employed as a technology for wireless mesh networks and can put up longer distance coverage with the help of cooperative packet relaying and this is superior to PMP mode. [3]

1.2 Multipath Routing and its Issues

The effective method to avoid congestion and losses in the networks is by multipath routing which is otherwise termed as alternate path routing (APR) and this technique provide improved capacity. The load balance obtained as result of traffic distribution among different paths is more enhanced and thus the performance can be improved. [4]

In order to perform the data splitting and transmission via two or more unlike paths to destination, multipath routing protocol is designed. The drawback is that multipath routing protocol cannot accomplish throughput due to the inter-intra flow channel competition and interference [5]

The main goal of multipath routing is to construct multiple paths to enhance fault tolerance and decrease routing overheads. The traditional multipath routing protocols causes flooding of routing control messages and congestion in gateways. [6]

1.2.1 Routing Control Messages Flooding

This issue occurs as route request is replied back by the intermediate node and the messages of route request starts flooding to the gateway and thus areas close to the gateway become congested.

1.2.2 Gateway Congestion

Gateway congestion is caused due to the flooding of the routing control messages and processing of added control messages. During data packet relay, gateway node should use more time to deal with the route request. [6]

The worsen situation of the congestion is faced by the multipath routing protocols during the transmission of data packets among the multipaths in the simultaneous manner. If multiple non-disjoint paths are chosen for transmitting the packet, deterioration occurs and the intersection node turns out to be the bottleneck [7].

The traffic forwarded over the multipaths causes jitter problem that further deteriorates the performance of real time applications [8]

1.3 Fault Tolerance

The fault tolerant system has two main steps

- 1.3.1 The different methods to detect the fault prevalence in WMN. This is significant since location of fault occurrence should be known in order to build the fault tolerant WMN.
- 1.3.2 The radio coverage plan to be made in the faults available scenario. [16]

1.4 Problem Identification

In paper [14] a distributed multi-channel assignment with congestion control (DMAC) routing protocol is proposed. In this protocol, a traffic aware metric provides solution for multi channel assignment and congestion control.

In paper [15] a priority based bandwidth reservation protocol (PBRP) for wireless mesh network is proposed. The protocol describes the bandwidth request and reply phase and destination node precedes the reply according to the priority of traffic classes and reserves the bandwidth on the reply path.

Both papers [14] and [15] focus only on congestion control, multi-channel assignment and bandwidth reservation and also the routing algorithm is not reliable. During the time of faults, the routing algorithm can’t deal with the faults immediately which may result in the packet loss and poor network quality of service (QoS) since it is single path.

Hence in this paper, we propose a fault tolerant multipath routing in 802.16 wireless mesh networks.

2. Related Works

Paramjeet Kaur Bedi et al [9] proposed a reactive hop-count based multipath routing protocol for wireless mesh network. This protocol is conscious about congestion and its immediate neighbor’s location. The nodes can select the links having sufficient bandwidth that is required for incoming flows with the help of congestion aware mechanism. This approach mainly focuses on the routing metric with fast route discovery, minimum hops, minimum delays, maximum data rates and minimum error rates.

Valeria Loscrì et al [10] proposed a multi-path parallel routing protocol (MPRP). MPRP permits creation of loop-free paths and using multiple path usage simultaneously. For evaluating the impact of the multiple paths, they take four different schedulers scheme into consideration which is designed for WMNs and these are time division multiple access (TDMA) based and totally distributed.

Zhiyuan LI et al [11] proposed a multipath routing algorithm based on the traffic prediction (MRATP) in wireless mesh networks. Initially wavelet neural network based traffic prediction model is built and based on this model MRATP is designed. The algorithm consists of three sections that includes multipath routing, wavelet-neural network based congestion discovery mechanism and load balance algorithm using multi-path.

Farah Kandah et al [12] proposed the interference-aware robust wireless mesh network design (INARI). This approach offers an heuristic approach that looks for robust network design which satisfies request of users by providing a pair of link-disjoint paths with minimum number of free link consumptions. The robustness in the network is provided with help of channel assignment scheme and link disjoint path scheme. This paper provides solution to the network link usage by maximizing the usability in the number of edges to provide more satisfied requests.

Bozidar Radunovic et al [13] proposed an optimization framework for addressing questions arising regarding multipath routing in the wireless mesh networks. The use of the network coding makes the approach more implicit, that facilitate to define the ideas of the credits used to track the number of transmission packets rather than specific packets themselves. This algorithm considerably outperforms the single path routing.

3. Fault Tolerant Multipath Routing Technique

3.1 Overview

In this paper, we propose a fault tolerant multipath routing in 802.16 mesh networks. The combined metric for interference avoidance (IAP) is designed with exclusive expected transmission time (EETT), interference load aware (ILA) and interference aware metrics (iAWARE). EETT characterizes the busyness of the channel with the link. ILA metric is used to find paths between the mesh routers and iAWARE takes into account the amount of traffic generated by interfering nodes. The distance among the neighbor nodes is calculated. The source node chooses the path with the minimum W (W = IAP * distance) as the primary path to the next hop. If there is failure notification in primary path, the alternate path is chosen that has the second minimum value of W. If fault condition disappears in alternate path, source node shifts to primary path. In case there is fault in alternate path also, source node chooses second alternate path that has next minimum value of W and this process continues and thus optimal path is selected for transmission.

3.2 Interference Avoidance Protocol (IAPij)

The wireless mesh networks are severely affected by the interference. Hence a routing metric should capture the potential interference experienced by the link to discover the paths that have minimum interference and enhances the overall network capacity.

We propose an interference avoidance protocol IAP_{ij} for a wireless mesh networks. It is designed with the help of following metrics.

- Exclusive Expected Transmission Time ($EETT_{ij}$)
- Interference Load Aware (ILA_{ij})
- Interference Aware ($iAWARE_{ij}$)

3.2.1 Exclusive Expected Transmission Time (EETTij)

EETT of a link i characterizes the busyness of the channel with the link i. The presence of several neighboring links on the same channel with link i causes the link i to remain for longer duration for the transmission to be executed over the channel. If the path has larger $EETT_{ij}$ value, rigorous interference is caused and it requires additional time to complete the transmission over all links within the path. [17]

EETT is computed as follows:

$$EETT_{ij} = \sum_{i \in s} ETT_i \quad (1)$$

where ETT_i represents expected transmission time to successfully transmit a packet at the MAC layer and it is defined as follows

$$ETT_{ij} = ETX_{ij} \times \frac{AvS}{Bw_c} \tag{2}$$

Where

AvS = average size of a packet

Bw_c = current bandwidth of the link.

ETX_{ij} = expected transmission count

Overall, ETT_i improves the throughput of the path via the measurements of link capacities and hence increases the overall performance of the network.

The expected transmission count metric (ETX) involves the process of conversion of the links success probabilities. It involves two steps

1) Average signal to noise ratio (SNR) estimation: With the help of information offered by the probe packets, this estimation is performed
2) Link success probability estimation: Using average value of SNR, link success probability is done.

The algorithm for estimating ETX at any rate for a link $i \rightarrow j$ is as follows.

Let P_{ij}, and P_{ji} be the probabilities,

R_s be the source rate,

R_t be the target rate and

Z be probe size

ER_p packet error rate

Step1

The success probabilities are transformed into the loss probabilities

$$\Delta P_{ij} \leftarrow 1 - P_{ij} \tag{3}$$

$$\Delta P_{ji} \leftarrow 1 - P_{ji} \tag{4}$$

Step 2

The SNR is estimated using following two ways

$$SNR_{ij} \leftarrow find\, SNR(\Delta P_{ij}, R_s, Z) \tag{5}$$

$$SNR_{ji} \leftarrow find\, SNR(\Delta P_{ji}, R_s, Z) \tag{6}$$

Step 3

Once again checking the table to get the error rate.

$$New\Delta P_{ij} \leftarrow find\, ER_p\,(SNR_{ij}, R_t, Z) \tag{7}$$

$$New\Delta P_{ji}{*} \leftarrow find\, ER_p\,(SNR_{ji}, R_t, Z) \tag{8}$$

Step 4

In this step, the loss probabilities are changed into success probabilities.

$$New P_{ij} \leftarrow 1 - New P_{ij}\ * \tag{9}$$

$$New P_{ji} \leftarrow 1 - New P_{ji}\ * \tag{10}$$

Step 4

Computation of ETX

$$New ETX_{ij} \leftarrow \frac{1}{(NewP_{ij} * NewP_{ji})} \tag{11}$$

This value of the ETX is utilized in the computation of ETT_i

3.2.2 Interference Load Aware (ILA)

The Interference-Load Aware metric (ILA) metric is utilized to discover paths between the mesh routers and two components included in them are as follows

1) Metric of Traffic Interference (MTI_i) and
2) Channel Switching Cost (CSC_i) .

Both intra-flow and inter-flow interferences are present in mesh networks. The MTI metric captures the inter-flow interference and this metric is considered in our approach. [18]

Metric of Traffic Interference (MTI)

In metric of traffic interference, the traffic load of the interfering neighbors is taken into account. The degree of interference is based on load generated by the interfering node. Thus MTI metric is defined as follows:

$$MTI_i(d) = \begin{cases} ETT_{ij}(d) \times AvL_{ij}(d), IN(d) \neq 0 \\ ETT_{ij}(d), IN(d) = 0 \end{cases} \qquad (12)$$

where $AvL_{ij}(d)$ = Average load of the neighbors which interferes during the transmission between nodes i and j over channel d.

$IN(d)$ = set of interfering neighbors of nodes i and node j.

$AvL_{ij}(d)$ is given by the following equation

$$AvL_{ij}(d) = \frac{\sum_{IN} L_{ij}(d)}{IN(d)} \qquad (13)$$

$$IN(d) = IN_i(d) \cup IN_j(d) \qquad (14)$$

where $L_{ij}(d)$ = load of the interfering neighbor.

The optimum path selection is selected by MTI based on the following condition

Condition 1

If interfering neighbor are absent
Then
MTI selects the path with high transmission rate and low loss ratio

Condition 2

If interfering neighbors are present
Then
MTI selects path with minimum traffic load and minimum interferences.

From the above description it is clear that MTI captures the inter-flow interference and it decreases the packet delay that is caused due to the load of neighboring nodes.

3.2.3 Interference Aware (iAWARE)

The interference aware (iAware) metric takes into account the amount of traffic generated by interfering nodes [19]. It is expressed using the following equation

$$iAWARE_p = (1-\delta) \times \sum_{i=1}^{n} iAWARE_i + \delta \times \max_{1 \le i \le d} H_j \qquad (15)$$

H_j = sum of the ETT values of links that are on channel j in a system that has d orthogonal channels and

δ = tunable parameter within the bounds $0 \le \delta \le 1$ that allows controlling the preference over path length versus channel diversity.

The *iAware* value of a link j is explained using the following equation

$$iAWARE_j = \frac{ETT_J}{I_j} \qquad (16)$$

where I_j represents interference ratio and its value for a link j between nodes s and t is given by the following equation

$$I_j = \min(I_j(s), I_j(t)) \qquad (17)$$

Thus the interference ratio (I) at a single node u for a link i is defined as follows.

$$I_i(s) = \frac{SINR_i(s)}{SNR_i(s)} \qquad (18)$$

where $SINR_i(s)$ = signal to interference noise ratio

$SNR_i(s)$ = signal to noise ration at node s for link i.

The $iAware$ metric develops the fact based on the occurrence of interference.

If interference = min,
Then
ETT metric captures link quality in a better way.
If interference = nil
Then
$iAware$ metric becomes ETT as $I \rightarrow 1$

3.2.4 Interference Avoidance Protocol

Based on the computation made in the section 3.2.1-3.2.4, we formulate a combined metric for avoiding interference which is given by the following equation

$$IAP_{ij} = \frac{EETT_{ij}(d) * AvL_{ij}(d)}{I_k} + IAR \tag{19}$$

where AvL_{ij} = Average load of neighbors. This hinders the transmission among nodes i and j over channel C and it is derived from equation (13).

I_k = Interference ratio for a link k and it based on the equation (18)

IAR = Total time period between the generation of a packet up to its successful transmission.

$EETT_{ij}$ = exclusive expected time which is derived based on the equation (1).

3.3 Multipath Routing

3.3.1 Multipath Discovery

Let N_j be the next hop node of the node N_i

The WMN topology is abstracted into n-node undirected graph $G = (N, E)$. The n-order square matrix and element in the matrix describes the adjacency matrix.

D = distance among neighbor nodes

$$C[i][j] = \begin{cases} D, if\,(N_i, N_j) \in E \\ 0, if\,(N_i, N_j) \notin E \end{cases} \tag{20}$$

The matrix $C[i][j]$ has the distance values in the ascending order stored in them.

The condition to choose next hop (N_j) is based on the following condition

```
For each $Ni$
        Let Path$[i] = \{N_i\}$
        For each $N_j$ of $Ni$
                Find $W_j = C[i][j] \times IAP$
                Sort $W_j$ in ascending order
                Select $N_j$ such that $W_j = \min(W_k)$
                Path$[i] = Ni \cup Nj$
        End for
End For
```

The source node chooses the minimum value of W for the purpose of transmission to the next hop as per the above condition which is the primary path P_1. Then the source node chooses the paths that have the next minimum values of W as backup paths P_2 and P_3. Initially the transmission takes place using primary path P1 and during any fault, it can be switched over the backup paths P2 or P3 (will be explained in the next section)

3.3.2 Fault Tolerant Routing

Let P_1 = Primary path

$P_2, P_3 \cdots P_n = alternate\ path\ 2,3 \cdots n$

The primary and alternate paths are set up from source to destination with the help of both distance among nodes and the metrics in the interference avoidance protocol.

The process by which the source node transmits the data packet to the destination through the available paths is as follows.

```
        3.3.1 Source node forwards the data packet through P1
        3.3.2 If there is any fault detection in P1
                Then
  Fault notification message is feedback to the source node in advance by the   intermediate nodes available in the paths.
                End if
3.3.3 After reception of fault notification, source node triggers P2 to transmit network traffic.
3.3.4 If fault condition disappears
    Then
    P2 is disabled and primary path is only used for transmission of data.
Else if source receives fault notification from P2
Then
Source activates P3 to transmit traffic.
    End if
```

4. Simulation Results

4.1 Simulation Model and Parameters

We use NS2 [20] to simulate our proposed protocol. We use the IEEE802.16e simulator [21] patch for NS2 version 2.33 to simulate a WiMAX Mesh Network. It has the facility to include multiple channels and radios. It supports different types of topologies such as chain, ring, multi ring, grid, binary tree, star, hexagon and triangular. The supported traffic types are CBR, VoIP, Video-on-Demand (VoD) and FTP. In our simulation, mobile nodes are arranged in a ring topology of size 500 meter x 500 meter region. We vary the number of nodes from 5 to 25. All nodes have the same transmission range of 250 meters. A total of 4 traffic flows (two VoIP and one VoD) are used.

Our simulation settings and parameters are summarized in table 1.

Table 1. Simulation Settings

No. of Nodes	5,10,15,20 and 25
Area Size	500 X 500
Mac	802.16e
Radio Range	250m
Simulation Time	100 sec
Traffic Source	VoIP and VoD
VoD Packet Size	65536
VoD Rate	100Kb
VoIP Codec	GSM.AMR
No. of VoIP frames per packet	2
No.of Traffic Flows	1,2,3,4 and 5
Topology Type	Ring
OFDM Bandwidth	10 MHz

4.2 Performance Metrics

We compare our Reliable Multipath Routing (RMR) protocol with the MPRP [8] protocol**.** We evaluate mainly the performance according to the following metrics, by varying the simulation time and the number of channels.

- **Average end-to-end delay:** The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.
- **Average Packet Delivery Ratio:** It is the ratio of the number of packets received successfully and the total number of packets sent
- **Overhead:** It is the control overhead measured in packets

A. Based on Nodes

Initially we vary the number of nodes as 5,10,15,20 and 25.

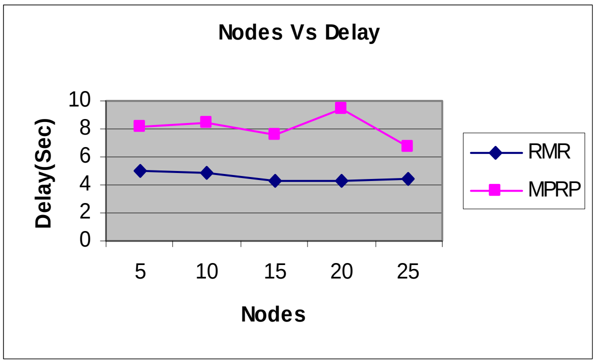

Fig .1. Nodes Vs Delay

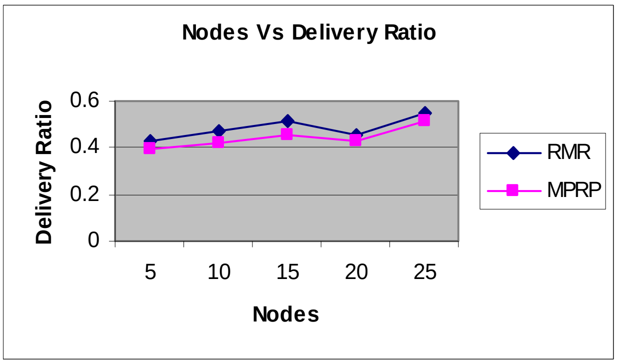

Fig .2. Nodes Vs Delivery Ratio

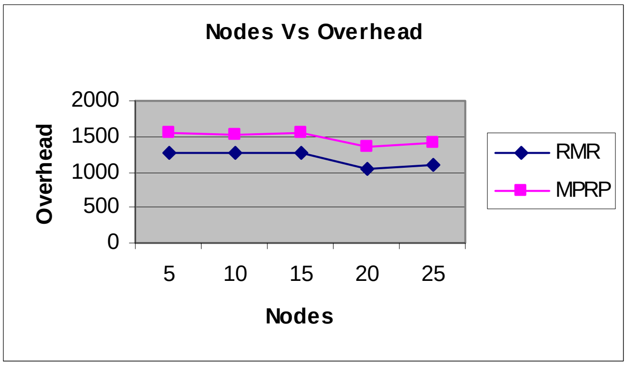

Fig .3. Nodes Vs Overhead

From Fig 1, when the number of nodes increases, the average end-to-end delay also increases. We can see that the average end-to-end delay of the proposed RMR protocol is less when compared to the MPRP protocol.

Fig 2 presents the packet delivery ratio of both the protocols. When the number of nodes increases the packet delivery ratio decreases. We can observe that RMR achieves good delivery ratio, when compared to MPRP.

Fig 3 gives the overhead of both the protocols when the number of nodes is increased. When the number of nodes increases the overhead decreases. As we can see from the figure, the overhead is more in the case of MPRP than RMR.

B. Based on Traffic Flows

In our second experiment we vary the number of traffic flows as 1,2,3,4 and 5 with 25 nodes.

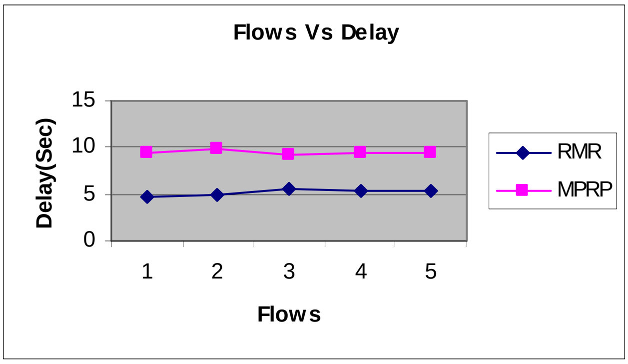

Fig .4. Flows Vs Delay

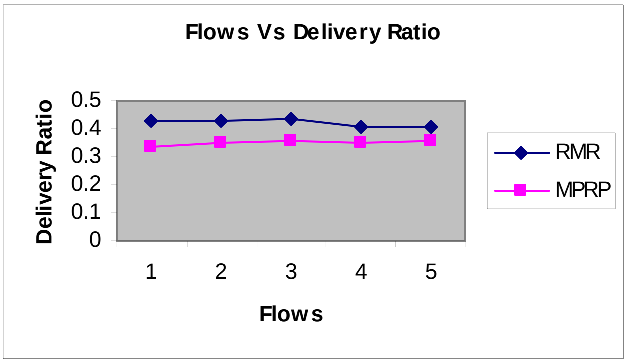

Fig.5. Flows Vs Delivery Ratio

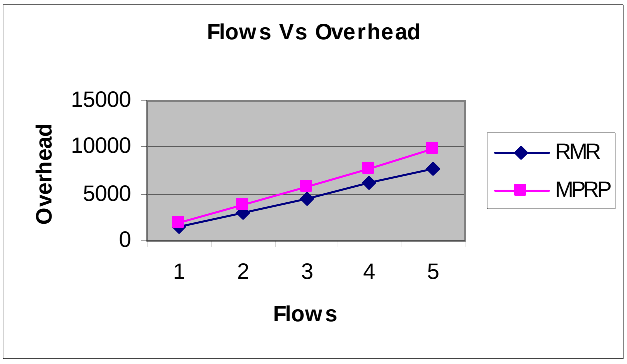

Fig .6. Flows Vs Overhead

From Fig 4, when the number of traffic flows increases, the average end-to-end delay also increases. We can see that the average end-to-end delay of the proposed RMR protocol is less when compared to the MPRP protocol.

Fig 5 presents the packet delivery ratio of both the protocols. When the number of traffic flows increases the packet delivery ratio decreases. We can observe that RMR achieves good delivery ratio, when compared to MPRP.

Fig 6 gives the overhead of both the protocols when the number of traffic flows is increased. When the number of traffic flows increases the overhead decreases. As we can see from the figure, the overhead is more in the case of MPRP than RMR.

5. Conclusion

In this paper, we have proposed a reliable multipath routing for IEEE 802.16 wireless mesh networks. The combined metric for interference avoidance (IAP) is computed based on exclusive expected transmission time (EETT), interference load aware (ILA) and interference aware metrics (iAWARE). The source node chooses the path with the minimum value of IAP and distance as the primary path to the next hop. If there is failure notification in primary path, the alternate path is chosen that has the second minimum value. If fault condition disappears in alternate path, source node shifts to primary path. In case there is fault in alternate path also, source node chooses second alternate path that has next minimum value of W and this process continues and thus optimal path is selected for transmission. By simulation results, we have shown that the proposed protocol provides better throughput with reduced delay and overhead.

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Malmurugan Nagarajan has around Twenty two years of both Teaching and Industrial experience. He worked extensively in Audio, Video Codec development for mobile platforms and well versed with Audio and Video standards. He is strong in developing tools & system applications and Modeling & Simulation. Currently he is developing new algorithms and IPs for the components in Wireless Broadband Physical Layer He is an Educationist and held various positions ranging from Lecturer to Principal in various educational organizations. His area of interest includes Wavelet variants based Signal and Image Processing, Multimedia Compression & Watermarking, Signal Processing algorithm development in Telecom domain. He is Member of IEEE, Fellow of IETE, Fellow of UWA and Editor of Journal of Simulation and Modeling