IOBR:Interoperable Bee-Hive Routing in a Heterogeneous Multi-Radio Network

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***Abstract*—WiMAX and WiFi are the two proliferating wireless technologies with different physical and Media Access Control (MAC) layers. Today, WiFi radio is present in almost all the devices, and most of the devices are equipped with WiMAX radio. Both these technologies can be utilized, if the devices are equipped with both of them, to improve the performance. To cope up with the scenario, a method for routing in a heterogeneous infrastructure based mesh network is proposed. The heterogeneous network consists of a coordinator node and a subscriber node. In this paper, we assume that the coordinator nodes are equipped with both WiMAX and WiFi radios, whereas, the subscriber nodes need not have WiMAX radio. The protocol used for routing data is based on the bee-hive algorithm, in which the entire network is divided into foraging zones/regions. We propose a technique in which the intra-foraging zone communication happens through WiFi and the nodes across the foraging zone communicate via the coordinator using WiMAX. It is observed through simulations that our technique improves the overall network performance by making use of both the radios efficiently.**

I. INTRODUCTION

WiMAX (Worldwide Interoperability for Microwave Access) is a wireless MAN standard approved by the IEEE 802.16 group. It supports point-to-point (P2P) and point-to-multipoint (PMP) standards that delivers last mile broadband connectivity and provides a data transfer rate of upto 100 Mbps [1]. WiMAX covers a range of upto 30 miles [2] and operates in 10 to 66 GHz [2]. The standard defines both the physical as well as the Media Access Control (MAC) layers.

WiFi (Wireless Fidelity) is a wireless LAN standard based on the IEEE 802.11. It is used for last mile connectivity and provides a data transfer rate of upto 244Mbps [3]. It covers upto 1km [3] and operates in 2.44 GHz to 5 GHz [2] unlicensed frequency band.

An infrastructure based network consists of a base station or a coordinator node that acts a centralized control for communication. The subscriber nodes in the network communicate with each other through the coordinator. Each message from a sender subscriber node goes directly to the base station from where it is forwarded to the destination subscriber node. A mesh network is one in which the nodes form a network with each other and communicate directly. There is no centralized control in a mesh network. In our work, we have assumed that the coordinator nodes are equipped with both WiMAX and WiFi radios whereas the minimum requirement for a subscriber node is a WiFi radio. Interoperability between various technologies has been an ever-growing area and our work concentrates on the interoperability between WiMAX and WiFi technologies using the bee-hive routing algorithm. Bee-hive algorithm is based on the social behaviour of the honey bees where the bees communicate the distance, direction and quality of the discovered food source to other bees by means of a waggle dance on a dance floor in the bee hive. The bio-inspired algorithm is robust, scalable, fault-tolerant and heavily depends on the local information.

An illustration of the network is shown in Figure 1. In our paper, the coordinator nodes are represented by upper case letters such as *A* and the subscriber nodes are represented by lower case letters such as *x*. In Figure 1, there are three regions and as can be seen from the figure, the subscriber node *x* does not belong to any of the regions. Such a case, where a node initially does not belong to any of the regions, is taken care of in our work. When the node *u* wishes to communicate with node *w*, the communication happens through the intermediate node *v* since both *u* and *w* belong to the same foraging region. In this case, the behaviour is analogous to that of a mesh network. When the subscriber nodes *u* and *s* desire to communicate with each other, the data from node *u* is first forwarded to its coordinator *C* which sends the data to the coordinator *A* which finally forwards it to the destination node *s*. In this case, the data takes the path through the coordinators since the nodes *u* and *s* do not belong to the same foraging region. Here, the behaviour of the network is similar to that of an infrastructure-based network.

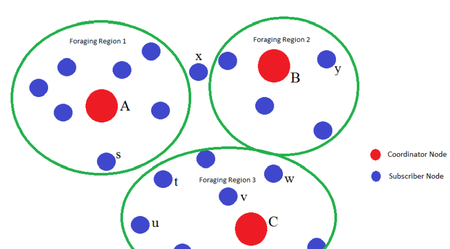

Fig. 1: *Node Model of the Coordinator Node*

The simulations are performed using the OPNET Modeller,

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a user-friendly simulator with enormous features that support general network modelling for both communication networks as well as distributed systems.

II. RELATED WORK

Work on interoperability between WiMAX and WiFi are numerous, which are discussed in [4], [5], [6]. Interoperability of WiMAX and WiFi was exploited to enhance the throughput in [7]. The evaluation of end-to-end issues and quality of service in interoperability is discussed in [8]. A technique for interoperability at the Media Access Control layer is proposed in [9]. [2] and [3] compare WiMAX and WiFi technologies. A protocol to route in the wireless medium using WiMAX and WiFi radios is projected in [10]. Routing in multi-radio, multi-hop wireless mesh networks is discussed in [11] and [12]. [13] discusses the concept of swarm intelligence. This paper is based on the bee-hive routing algorithm [14] which is inspired by the behaviour of honey bees. [15] gives a survey of the bee-hive algorithm. In [16], the bee-hive algorithm is used to perform fault-tolerant routing.

III. PROBLEM STATEMENT

In this section, we wish to portray the problem at hand that is to be addressed. The primary goal is to efficiently utilize both the WiMAX and WiFi radios to route the data and thereby improve the performance of the network. We design an infrastructure-based mesh network as shown in Figure 1, implement the bee-hive routing algorithm and analyze the performance.

IV. DESIGN AND IMPLEMENTATION

The network consists of coordinator nodes and subscriber nodes. The coordinator nodes are equipped with both WiMAX and WiFi radios and the node model of the coordinator is as shown in Figure 2.

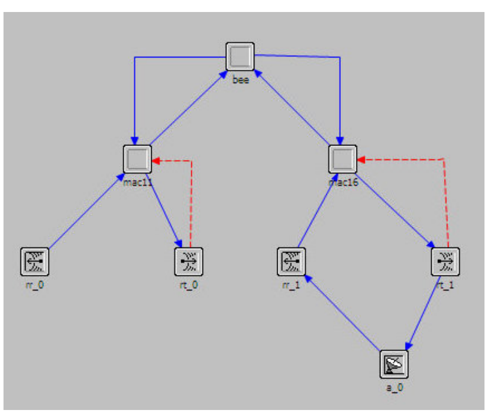

Fig. 2: *Node Model of the Coordinator Node*

- $beeLayer$: It is analogous to the Network layer of the protocol stack. The routing decisions are taken here.
- $mac11Layer$: This corresponds to the Media Access Control layer in the Data Link layer of the protocol stack and implements IEEE 802.11. It represents the WiFi radio of the coordinator node.
- $mac16Layer$: It also corresponds to the Media Access Control layer in the Data Link layer of the protocol stack but implements IEEE 802.16. It represents the WiMAX radio of the coordinator node.
- Both the MAC layers implement the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm. Not much emphasis is given to the details of its implementation in this paper.
- rr_1, rt_1, rr_0 and rt_0: Radio receivers and radio transmitters corresponding to the WiMAX and WiFi radios respectively.
- a_0: Antenna for the WiMAX radio.

Each coordinator node maintains two types of routing tables:

Long routing table

The long routing table maintains the information about all the coordinator nodes, which includes the next hop, the hop count and the list of all the subscriber nodes in each coordinator's region. All the routing done using the information derived from this table is through WiMAX channel. The structure of the table is as shown in Table I.

TABLE I: *Long Routing Table*

Coordinator Node ID	**Next Hop Coordinator Node**	**Hop Count**	**List of all subscriber nodes in this region**

Short routing table

The short routing table contains the list of all the nodes in its region along with the next hop and the hop count to each node. The structure of the short routing table is as shown in Table II:

TABLE II: *Short Routing Table*

Subscriber Node	**Next Hop**	**Hop Count**

The subscriber nodes have the following layers implemented as shown in Figure 3.

- $srcLayer$: This layer is analogous to the Application layer in the OSI architecture. It produces data packets required for testing the effectiveness of the protocol during the simulation. The data packets produced here do not have any destination address attached to them. An

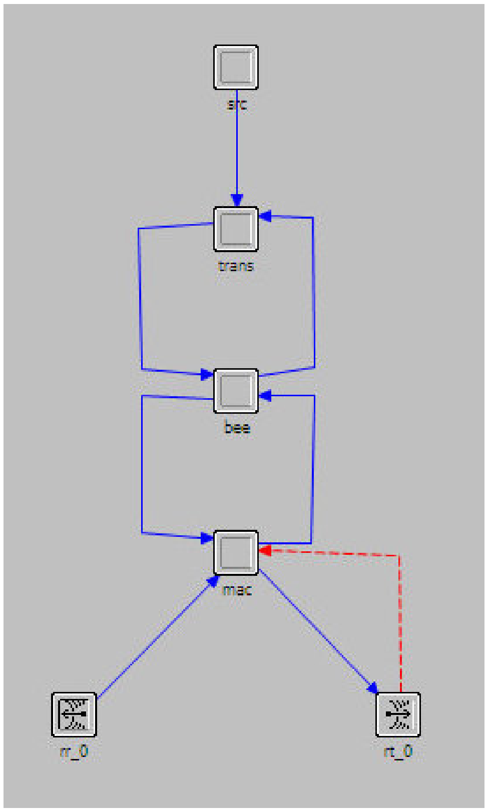

Fig. 3: *Node Model of the Subscriber Node*

inbuilt OPNET process model is made use of for this purpose.

- $transLayer$: The trans layer corresponds to the Transport layer of the protocol stack.
- $beeLayer$: The bee layer takes care of the routing decisions to be made.
- $macLayer$: The mac layer is the Media Access Control layer of the node and is implemented using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). It is the IEEE 802.11 radio.
- rr_0 and rt_0: Radio receiver and the radio transmitter of the WiFi radio.

Each subscriber node maintains a routing table containing the list of nodes in its region inclusive of the coordinator along with their corresponding next hops and hop counts. The routing table follows the form shown in Table III.

TABLE III: *Routing Table*

Node	Next Hop	Hop Count

Foraging Region

The overall network is divided into foraging regions in order to reduce the traffic and increase the throughput. The foraging zones are formed based on the hop-count. All the nodes within a hop-count of n from the coordinator are considered to belong to one foraging region; where n is a parameter defining the size of the foraging region, and can be decided based on the overall network size. In addition, any node that is not within a foraging zone, but is reachable by any of the subscriber nodes in a foraging zone, is added to the same foraging zone. If there are many such nodes, the node is added to the region of the nearest node.

Routing

Within the Region: The subscriber nodes are equipped only with WiFi radio, hence the communication between the subscriber nodes and the coordinator node or any other subscriber node happens through the WiFi channel. Within the region, every node has access to every other node, that is, every node knows the address of and the next hop to be taken to every node in its region.

Outside the region: The coordinator nodes are equipped with both WiMAX and WiFi radios. Hence, the coordinator nodes communicate among themselves via the WiMAX channel. All the coordinators know the address of and the next hop to all other coordinator nodes, as well as the list of all subscriber nodes in each coordinator node's region. When a node x desires to send a packet to a node y in another region, node x first searches for node y in its routing table, and realizes that node y does not belong to its region when it does not find an entry corresponding to node y in its routing table. It then forwards the packet to its coordinator A. The coordinator node A searches for the destination in its long routing table and forwards the packet to the corresponding next coordinator node B via WiMAX channel. Node B searches for node y in its short routing table. If it is found (which happens if node y belong to the coordinator B's region), the packet is forwarded to node y via the WiFi channel. If it is not found, then the search is done in coordinator node B's long routing table and the process continues till the packet reaches the node y. This process is depicted in Figure 1.

Establishment of the Subscriber Nodes' Routing Tables

Initially, while forming the foraging region, the coordinator node gets the list of all the nodes in its region and broadcasts this information to all the nodes in its region. On receipt of this broadcast, all the nodes create their routing tables containing the entries for the list of nodes sent by the coordinator node. The next hop to each node is updated as the next hop to the coordinator node. The hop count is set equal to the sum of the number of hops from this node to the coordinator node and the number of hops from the coordinator node to the destination node whose entry is being added. Each node has the hop count corresponding to its own entry in the routing table as 0.

Once the initial routing table is created, the nodes exchange their routing tables within the region, hence updating the next hop and the hop count entries. The nodes compare the hop count in the received routing table with that in their own routing table for each entry. If node x, a neighbour of node y receives a packet from y, the hop count corresponding to y in the packet is 0, whereas, that in its routing table is more (the initial path is via the coordinator). Hence, this entry in the routing table is updated to 1. The updated routing table is then forwarded to other nodes. Hence the routing tables of all the nodes converge to the right routes.

Establishment of the Coordinator Nodes' Routing Tables

The *short_routing_table* is created simultaneously with the process of forming foraging regions. The *long_routing_table* of the coordinator is created and updated by exchanging the corresponding *short_routing_tables*.

Each node has *region_number* and *node_objID* as its attributes. In addition, the coordinator node maintains the *nodes_count* which specifies the number of subscriber nodes in its region.

The algorithm for the coordinator node is shown in Algorithm I.

ALGORITHM I: *Coordinator Node*

Step 1: Broadcast *register* packet
Step 2: Upon reply from the node, add that node to its *short routing table*
Step 3: Send *short routing table* to all nodes in its region via WiFi radio
Step 4: Exchange *short routing table* with other coordinators via WiMAX radio
Step 5: On receipt of *short routing table* from another coordinator, update its *long routing table*
Step 6: Route data packets according to the entries in the *short* and *long routing table*

Each subscriber node runs Algorithm II.

ALGORITHM II: *Subscriber Node*

Step 1: On receipt of the *register* packet from the coordinator, acknowledge to it, so that it is added to the region
Step 2: If this node does not belong to a region, request the nearest reachable node to add this node to its region
Step 3: On receipt of the *short routing table* from the coordinator, create its *routing table*
Step 4: Exchange the *routing table* with other subscriber nodes in its region and hence update it
Step 5: Route data packets according to the entries in its *routing table*

V. PERFORMANCE ANALYSIS

The simulation was run for the topology shown in Figure 4 for 1 hour and the throughput and delay graphs as shown in Figure 5 and 6 were obtained. The coverage range of WiMAX and WiFi were considered to be 5000 meters and 750 meters respectively.

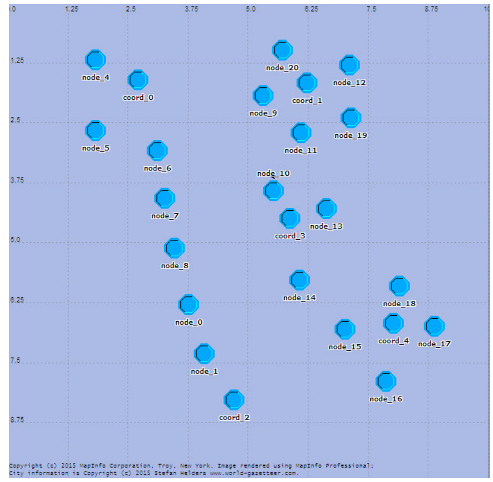

Fig. 4: *Network Topology*

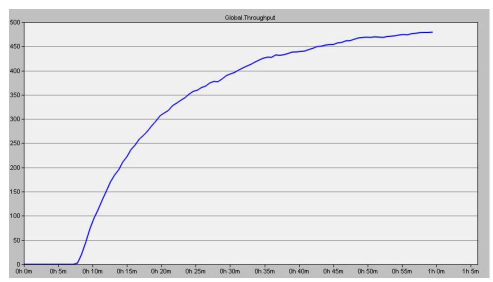

Fig. 5: *Graph of Throughput versus Time*

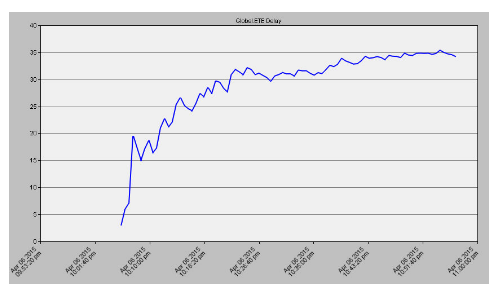

Fig. 6: *Graph of Delay versus Time*

The simulation was also performed on the same network using only WiFi channel to route the packets. The throughput and delay graphs were obtained and a comparison of both the scenarios is shown in Figures 7 and 8 respectively. It can be seen from Figure 7 that the throughput increases considerably when WiMAX radio is used for communication between the coordinator nodes. This is attributed to the longer coverage range of WiMAX than that of WiFi. The graph in Figure 8 shows the comparison of the end to end delay between the two scenarios. The delay when the coordinator nodes are equipped

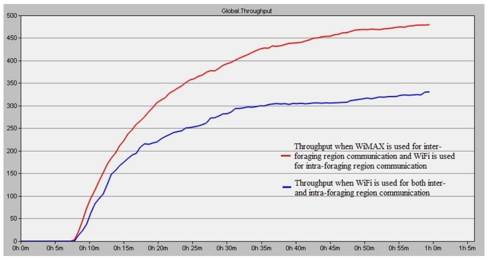

Fig. 7: *Comparision of throughput graphs*

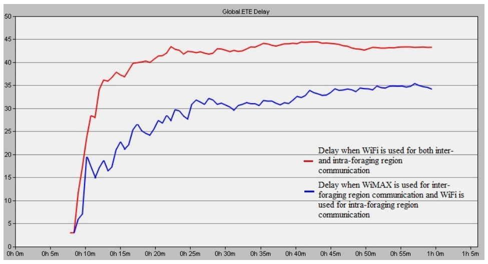

Fig. 8: *Comparision of delay graphs*

with both WiMAX and WiFi is observed to be lesser than the delay when all nodes are equipped with only WiFi radios.

VI. Conclusion

WiMAX and WiFi are two wireless technologies that can be used simultaneously for communication to increase the throughput and reduce the delay. In our work, we consider a heterogeneous infrastructure-based mesh network, where the coordinator nodes are equipped with both WiMAX and WiFi radios, and the subscriber nodes have only WiFi radio. The communication between the coordinators occurs via the WiMAX radio. The communication between any two subscriber stations or between a coordinator node and a subscriber station happens through the WiFi channel. Also, any subscriber node that cannot be directly included by the coordinator into its region is made reachable to the coordinator through a reachable subscriber node. Hence the algorithm tries to include all the nodes into regions, involving them into communication. There is an increase in throughput by a considerable amount due to the use of WiMAX channel.
As a part of the future work, the algorithm can be extended to mobile coordinator nodes and mobile subscriber nodes. The dependency of throughput on the value of the number of hops from the coordinator node that form one region can be determined.

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