Fault Tolerant BeeHive Routing in Mobile Ad-hoc Multi-radio Network

Kiran K, P Deepa Shenoy, Venugopal K R
Department of Computer Science and Engineering,
University Visvesvaraya College of Engineering,
Bangalore, India.

Lalit M Patnaik
Honorary Professor,
Indian Institute of Science
Bangalore, India.

Abstract— **In this paper, fault tolerance in a multi-radio network is discussed. Fault tolerance is achieved using the BeeHive routing algorithm. The paper discusses faults added to the system as random fluctuations in hardware radio operation. The multi-radio nodes are designed using WiMAX and WiFi Radios that work in conjunction using traffic splitting to transfer data across a multi-hop network. During the operation of this network random faults are introduced by turning off certain radios in nodes. The paper discusses fault tolerance as applied to multi radio nodes that use traffic splitting in the transmission of data. We also propose a method to handle random faults in hardware radios by using traffic splitting and combining it with the BeeHive routing algorithm.**

Keywords- Ad-hoc Wireless Networks, BeeHive Routing, Fault Tolerance, Multi-Radio Nodes, Multi-hop Networks, Traffic Splitting, WiFi, WiMAX.

I. INTRODUCTION

In all modern systems, fault tolerance has come to be expected as a necessary feature. Faults can be due to network issues, node or protocol issues or even environmental issues. In this paper we discuss Fault tolerance in multi-hop, multi-radio networks when faults arise due to random malfunctions in hardware radios[1]. We discuss the use of the BeeHive routing algorithm that helps in reducing transmission errors. Our main intention is the analysis and simulation of fault tolerance in a multi-radio node in a multi-hop network where routing is performed through the BeeHive routing algorithm. The multi-radio nodes consist of a WiFi and a WiMAX radio through which data is transmitted using traffic splitting.

WiFi is a popular name that is associated with devices that have the IEEE 802.11 standard of radios. WiMAX is again a name given to the IEEE 802.16 radio standard. WiMAX stands for Worldwide Interoperability for Microwave Access and it is a technology for point to multipoint wireless networking and is often employed in last mile broadband wireless service.

Fault tolerance in multi-radio nodes is tested during radio failure[2]. Here we discuss the effects of such a scenario and propose a method to handle such a condition during network operation. We also look at the problem of mobile nodes in a scenario consisting of faulty radios.

Traffic splitting is a technique for data transmission wherein data is split at the transmitting node before being transmitted over the network. Traffic may be split based on different criteria, of which few could be network congestion, radio failure, shortest path availability, bandwidth, etc. The benefits of traffic splitting include: better use of available radio resource, throughput enhancement and the consequent reduction in the transmission time.

The problem of traffic splitting tends to get complicated when mobility is added to the network. The problem of mobility must be tackled by every routing algorithm especially those that are applicable to wireless Ad-hoc networks.

In recent years the routing problem in wireless networks has become a fruitful area of research. Of the many routing protocols that have been introduced in recent years, one of the most interesting classes of optimization protocols that use the behavior of various insects to solve the routing problem are collectively called Swarm Intelligence. We use the BeeHive routing[3] algorithm in this paper and verify its fault tolerant ability in a multi-hop, multi-radio node wireless ad-hoc network[4], [5].

The paper is divided into four sections. In Section II, we present the literature survey and discuss other related works. In Section III, we describe the problem of fault tolerance in a multi-radio, multi-hop network and present an analysis of how traffic splitting affects the problem. In Section IV, we present the results of the simulations. We conclude in Section V, with the results and analysis of the simulations and with the work planned for the future.

II. RELATED WORK

Fault tolerance in wireless networks is a challenge not only because of the medium of transmission but also due to the nature of networking device interface. Fault tolerance is applicable to networks that have a greater chance of failure and naturally wireless networks, especially wireless Ad-hoc networks, fall conviniently into this category. Indeed fault tolerance in wireless networks brings with it several factors that make it a challenge[1].

Traffic splitting brings with itself other problems which require optimized channel sensing and selection of split criteria. Traffic splitting optimization discussed in [6] describes a method of performing channel sensing to optimize traffic

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splitting and improve throughput. In [7] we presented an analysis of traffic splitting when data traffic is split statically at the source node. The models showed an improved throughput curve and reduced delay due to traffic splitting. We performed simulations based on the model built in [7] and the results were presented in [8]. The results from the simulations showed the verification of the modeling.

The majority of work carried out at present relating to traffic splitting discusses methods and mechanisms to transmit data over homogeneous channels[9],[10],[11]. Some research in heterogeneous channels has been done and these works discuss the challenges faced during data transmission through traffic splitting using conventional routing algorithms.

Swarm Intelligence[5] is a collective name for networks that employ methods extrapolated by studying swarming insects for routing data traffic. One of these methods is BeeHive Routing which divides the network into foraging regions. The routing packets then form channels that optimize routing paths in these foraging regions.

The majority of work done in Swarm Intelligence and Routing mechanisms based on swarming intelligence does not cover the issue of fault tolerance in Traffic Splitting networks. The present work builds on [7], [8] and [3]. We aim to understand the issue of fault tolerance in networks where traffic splitting is employed for data transmission.

III. PROBLEM STATEMENT

In this paper, we aim to work on the problem of fault tolerance in hybrid nodes which use traffic splitting mechanism for the transmission and reception of data. The schematic of the hybrid node design is shown in Figure 2. The node shown in Figure 2, describes a multi-radio node which implements traffic splitting in the transport layer.

The aspect of the fault tolerance problem that we deal with concerns mainly with hardware radio related faults and its affect on the overall performance of the network in terms of data throughput and delay. The traffic splitting problem is dealt with in [7] and [8]. Our approach in the present problem builds on [7].

In this work, fault tolerance of the network is tested on random failure of node radios. In the event of failure of a WiFi radio in a node, the data split at the transport layer for the WiFi radio section is transmitted through the WiMAX radio section. All nodes in the network scenario are similar and have the same schema as shown in Figure 2. Figure 1, shows the network scenario containing Hybrid nodes.

These Hybrid nodes transmit data using a WiFi and a WiMAX radio channel. During the transmission of data over a particular route, a hardware radio fault occurs at one of the radios. In Figure 1, two paths for data transmission are shown. The route from A to B goes through F_1. Node F_1 has a hardware fault in its WiMAX radio section. To overcome the hardware fault in node F_1's WiMAX radio the node transfers its data packets to its WiFi radio module. Since, node F_1's WiFi module already has a path to B in its routing table data traffic is transmitted through the WiFi radio channel.

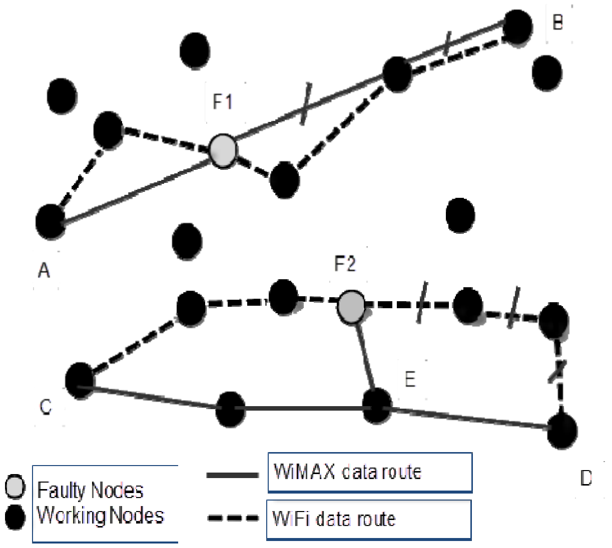

Figure 1. An Example network fault scenario showing initial routes.

A similar case is seen in the route between nodes C and D. The faulty node here is F_2, but in this case since node F_2 does not have a route to D through the WiMAX radio channel, a new route is created through the node E. The node under fault sends an error message to its neighbours, which causes data traffic designated to be transmitted over the faulty radio channel to be switched over at the transport layer to the non-faulty radio channel.

This mechanism is not sufficient to solve the entire problem. The predecessor nodes must also be informed that data transmission will be lost in the radio channel. We therefore introduce a *BEE2* message that informs predecessor nodes in the route regarding the status of the hardware radio at fault at a particular node.

Consider a network of N nodes, with radios R_1 and R_2. If a route exists from node M_1 to M_K, and a node M_F, has a fault in its radio R_1, the node M_F, sends a *BEE3* message to the predecessor nodes in the route about the condition of the radio R_1 through R_2. The nodes that receive the *BEE3* message, transfer the data to node M_F, from their R_1 modules to the R_2 Modules and continue transmission to M_F node. Another scenario that was expected was that of radio recovery. Although unlikely but if radio R_1 were to recover from a failure, another message *BEE4* was sent that informed predecessor nodes about the availability of the node to expect data through radio R_1.

The measures for the efficiency of this method are the effects on the overall network throughput and delay. BeeHive routing is chosen for use in this work due to its fault tolerant capability. The node shown in Figure 2 implements the BeeHive routing algorithm in the network layer. The transport layer shown in the Figure 2 implements the traffic splitting logic.

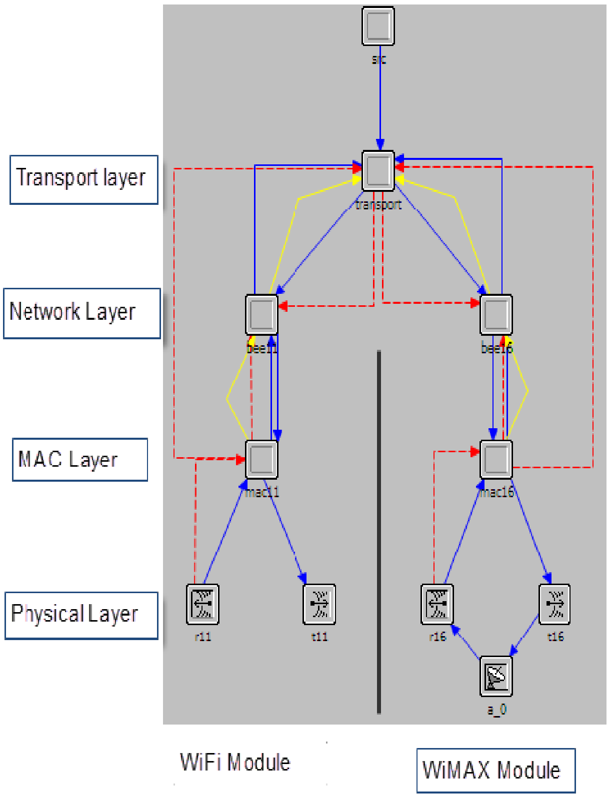

Figure 2. Hybrid Node Layered Design

IV. ANALYSIS AND SIMULATION RESULTS

The simulations were carried out in Opnet Modeler. The simulation network scenario is shown in Figure 3. In order to simulate radio faults in the node, the node radios were switched off at random time intervals.

Algorithm 1: Fault Tolerance in BeeHive Routing

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Mac layer on receiving interrupt from radio, obtains RADIO state and informs bee and transport layers.

If RADIO is OFF then
    Mac and Bee layers send all packets waiting for transmission to higher layers so that they can be transmitted from other side whose RADIO is ON.

Bee layer on side where RADIO is ON:
    Generates BEE3(Route Error) packet and sends to all neighbors to inform that the RADIO is OFF

When the packets from RADIO OFF side with unknown paths to destination arrive at the other side, a new route request will be initiated using BeeHive algorithm.

Any node on receiving BEE3 will transfer that packet to the other radio module of the node.

It makes the node in Routing table unreachable by setting valid=0 and retransmits the BEE3 packet to its neighbors for informing that a node has gone down and ask those nodes to find alternate paths.

If RADIO RECOVERS from FAULT then
    Bee layer generates and sends BEE4(Node Recovered) packet stating that radio fault is recovered.

When BEE4 is received by any neighbor node
    It updates the routing table that the node is reachable by setting valid=1 and transmit the packet to its neighbors, to inform their neighbors, that the node has recovered.
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Algorithm 1, described the methodology of fault tolerance in BeeHive routing when implemented in a hybrid node(shown in Figure 2) implementing traffic splitting. The algorithm allows nodes which are affected by the fault to continue transmission using the radio module that is not in fault. Thus, allowing data to be transmitted without very large gaps in interruption. The delay in resuming data transmission during a radio fault is not very large as is seen when comparing graphs shown in Figures 4 and 5.

Figure 3. Network Scenario for Simulation Run.

TABLE I. SIMULATION RUN METRICS

Radios	Parameters for Simulation Run	
	Raw Data Rate	***Radio Range***
WiMAX	2Mbps	2400m
WiFi	54Mbps	500m [15], [16]

The simulation network scenario is shown in Figure 3. The network consists of 29 hybrid nodes arranged in a mesh network. The radio parameters for the network are shown in Table I. The WiFi radios are set to have a raw data rate of 54Mbps and WiMAX radios are set to a raw data rate of 2Mbps. The comparative range of the radios is set such that WiMAX radio range is almost five times that of WiFi radio range in the simulations. This is done to keep the range of the radios comparable to real world scenarios.

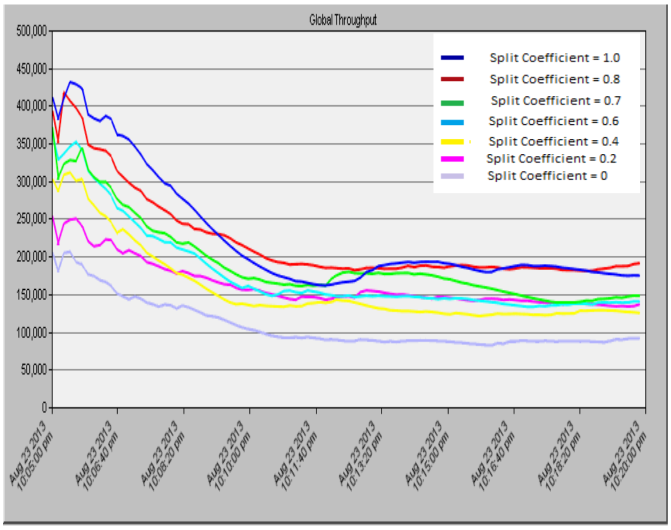

Figure 4. Throughput (bps) Vs Time Scenario: Scenario No Nodes at Fault

In order to compare the measure of the algorithm efficiency we simulate a scenario where the node has no radio fault. The throughput graphs of this scenario are shown in Figure 4. The graphs were drawn for different values of initial split coefficients[8]. As seen from the graphs the split coefficients tend to alter the throughput curves at the start of simulation, but the throughput then normalizes to some steady value in all cases. It is to this case of data throughput that the faulty cases were tested.

In the next simulation scenario, radio hardware faults are added to nodes at random durations to observe effects of radio hardware faults on network performance. These faults are then corrected in the simulator for some nodes to check for fault recovery using Algorithm 1. The graph for this scenario is shown in Figure 5. Also the end to end delay is shown in Figure 6.

The comparison of these graphs show that the reduction of throughput in the scenario where faults were introduced to the nodes does not decrease by a great amount. That goes to show that the algorithm does not allow great delays in resuming data transmission in the network. The graphs were plotted for various values of split coefficient which were randomly assigned at initialization of simulation.

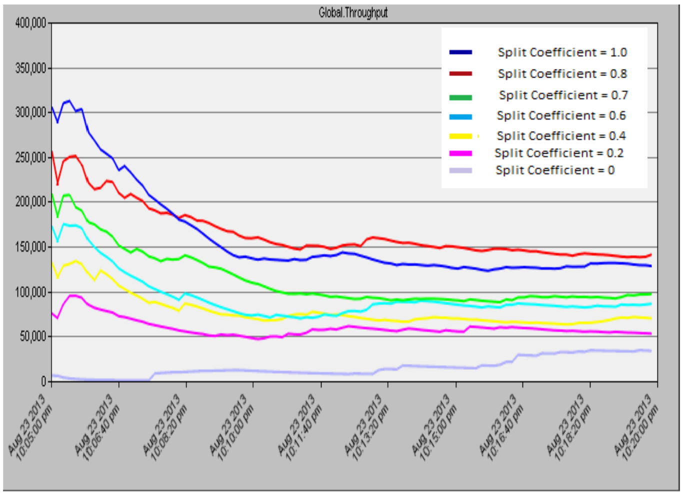

Figure 5. Throughput (bps) Vs Time: Node Fault Scenario

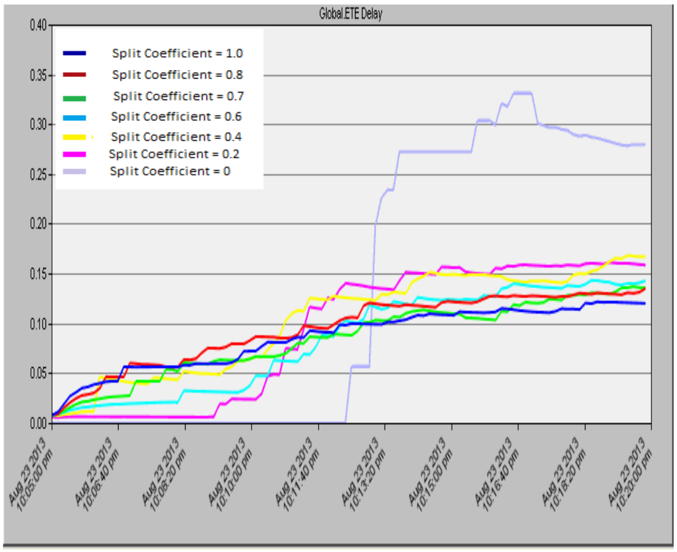

Figure 6.End to End Delay (Sec) Vs Simulation Time: Node Fault Scenario.

V. CONCLUSION AND FUTURE WORK

As seen from the results presented in the previous section, BeeHive routing was implemented in a wireless Ad-hoc network with traffic splitting. The results show that the algorithm developed for fault tolerance allows uninterrupted data transmission and fault recovery mechanisms. The efficiency of the mechanism measured in the graphs that were plotted show that the reduction in throughput is not significant and does not hamper network operation. As a future work we intend to work on self organizing networks that deal with automatic assignment of split coefficients for splitting data traffic. We also wish to compare other routing algorithms that will help us understand fault tolerance in wireless ad-hoc networks that use traffic splitting.

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