Analysis of Throughput in Infrastructure based Multi-Radio Network

Kiran K[1], Lakshmi B S[1], Priyanka Negi[1], Ramitha M[1], Shruthy S[1], P Deepa Shenoy[1], Venugopal K R[1], Lalit M Patnaik[2]
[1]*University Visvesvaraya College of Engineering*
[2]*Indian Institute of Science*

***Abstract*—**This paper deals with the design of an infrastructure based network consisting of Multi-radio Hybrid mobile nodes that perform traffic splitting over the network. The multi- radio mobile nodes have a WiMAX and a WiFi Radio that are used in transmitting data traffic over two different radio channels. Data traffic is split statically over a node and transmitted over the two radio channels. We analyse the Throughput and End-to-End delay for data transmission in the network.

Keywords*—Infrastructure based Network, Multi-Radio Mobile Nodes, Traffic Splitting.*

I. INTRODUCTION

An infrastructure based network comprises of a static router, base stations and mobile subscriber stations. The network is managed by the router which behaves as the centralized administrator. Base stations are connected to the router through point to point hardlinks. Subscriber stations are connected to the base stations through wireless network interfaces.

WiFi or Wireless Fidelity is a term that is generally used to refer to any product or service using any type of 802.11 Technology. WiFi enabled devices (laptops or PDAs) can send and receive data wirelessly from any location equipped with WiFi access. Access points, installed within a WiFi location, transmit RF signals to WiFi enabled devices that are within range of the access point, which is about 600m.

WiMAX is a broadband wireless data communication technology based around the IEEE 802.16 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.

In the previous papers throughput measurement by splitting the traffic between Wi-Fi and Wi-Max radios in an adhoc mesh network has been done. Here, an infrasucture based network is considered where nodes are either stationary or mobile and each node is equipped with both Wi-Fi and Wi-Max radios. Data from the nodes are split across the two radios and the traffic is routed independently.

In this paper, we present the results showing improvement in the throughput and end to end delay in an infrastructure based network on introduction of traffic splitting. The model is implemented on a Multi-Radio Hybrid node that performs traffic splitting over the radio channels. We employ WiMAX and WiFi radios in the Hybrid Multi-radio Nodes. In the remaining part of this section we give a brief introduction to the infrastructure based network. In Section II, we present a survey of related work. Subsequently, in Section III, we introduce the problem statement and define the essence of the present work. In Section IV we discuss the implementation of infrastructure based network. In Section V we present the description of the network models used for simulation. In section VI, the descriptions of the node models of the router, base station and the subscriber station is given. In section VII we present the results of the simulations and analyse the throughput and end to end delay. In Section VIII, we present conclusions and future work.

II. RELATED WORK

This paper is a result of work carried out on Traffic Splitting scenarios in an infrastructure based network having Hybrid Multi-Radio Mobile Nodes WiMAX and WiFi Radio channels for transmission of data.

The motivation of this research was from [1] and [2]. In [1] the authors have discussed the integration of Wi-Fi/WiMAX networks consisting of main and auxillary networks. The performance of the integrated network is compared with the "main" network. This paper focused on the integration gain that comes from the better utilization of the resource rather than the increase of the resource.

An analysis of Traffic splitting over an abstract Multi-radio, Multi-hop wireless mesh network has been done in paper [2] and the improvements in throughput are presented.

The study of improvement in the throughput has been done in paper [3] by splitting traffic over the two radio channels in an Ad-Hoc Network.

In paper [4] the challenge of link aggregation in a wireless terminal with multi-radio devices has been addressed. This paper proposes a feedback-based technique to determine split ratios adaptively, based on measurements at the receiver.

The paper [6] deals with the design of a Multi-radio Hybrid node that performs traffic splitting over a Multi-Hop Ad-hoc wireless network. It implements the AODV Routing protocol and the Beehive Routing algorithm on these nodes and considers the mobility aspect of the nodes. In [7] and [8] the authors deal with the use of traffic splitting in improving the performance of networks and [8] specifically discusses improvement in performing traffic splitting in heterogeneous links. In the design of heterogeneous infrastructure networks, the architecture and supporting features such as handoff are important. [9] discusses architecture of such a network with respect to the various challenges that mobility brings into heterogeneous networks. [10] and [11] deal with handover and mobility in heterogeneous networks.

In this paper, we focus on splitting data over multiple radios i.e WiFi and Wi-Max at a node in an infrastructure based environment. The network consists of a central router, stationary base stations and mobile subscriber stations. Different scenarios of the network, wherein different combinations of the network properties like split ratio, data rate and ranges are considered, are simulated in order to compare network performance in each of the cases. The emphasis is to analyze the simulations to find the properties for which the throughput is maximum.

III. PROBLEM STATEMENT

In this paper we discuss a mechanism for performing traffic splitting in an infrastructure network based on the Point Co-ordination Function. The main challenge here is to understand where and in which component of the network can traffic splitting make a difference in terms of throughput enhancement. The main objective of this paper is thus, to describe a mechanism to use traffic splitting in modern telecommunication infrastructure networks and to analyse it's effectiveness.

To achieve this objective we build an infrastructure based network consisting of hybrid mobile and static nodes and analyse the throughput by splitting the data across two radios: WiFI and WiMax.

The infrastructure networks we design in this paper is a generic infrastructure network based on the PCF and does not implement specific backend features of Wifi and Wimax Networks. We overlook the problem of soft handoffs in the infrastructure network design, providing support for only hard handoffs [12].

IV. IMPLEMENTATION

An infrastructure based network comprises of static nodes or a combination of static and dynamic nodes. The nodes can be classified at various layers making the whole network hierarchical in structure. The various layers can be connected either by wired point to point connections or by wireless interfaces.

The network comprises of a static router, base stations and static or mobile subscriber stations. The network is managed by the router which behaves as the centralized administrator. Base stations are connected to the router through point to point hardlinks. Subscriber stations are connected to the base stations through wireless network interfaces.

The subscriber station (SS) is a fixed or mobile wireless node which typically communicates with base stations. The SS are connected through wireless connections to the Base stations. The subscriber nodes in our network comprise of two wireless radio transceivers, namely, WiMAX and WiFi. Each radio transceiver on the node is full duplex and employs separate channels for transmission and reception.

The Base station is a fixed station, typically in a wireless network used for facilitating communication between subscriber nodes. It is responsible for handling traffic and signaling between subscriber stations.

The router plays the role of a central administrator. It keeps track of all the base stations and the respective subscriber stations in the network and facilitates communication among base stations.

The base station periodically registers all the subscriber stations within its range. Registration is done periodically to take into account the mobility of the subscriber stations. For each of the registered subscriber stations, it sends the Clear To Send (CTS) allowing it to transmit its data. On receiving CTS, the Subscriber station splits the data in a prespecified ratio and transmits it over the two radio channels to its base station. On receiving the data packets, the Base station transmits it over the hardlink to the router. The router maintains a table with entries for each Subscriber stations and their respective Base stations. This table is updated periodically. On receiving the data packets from a base station, it performs a look-up and sends it to the Base station in whose vicinity the destination Subscriber station is present.

The Base station, on receiving data packets from the router, splits it into two streams in a specified ratio and sends it to the destination subscriber station.

The nodes for the network are designed using Opnet Modeler. The Queues in the Hybrid Nodes are infinite M/M/1 Queues and are used to handle data flow from the higher layers of the node as well as incoming data from the network.

The Traffic Splitting layer is an abstraction of the Transport layer and is responsible for performing traffic splitting based on a Split Coefficient that is chosen at the start of every simulation run. These split coefficients are chosen to select a percentage of the data traffic to be routed over a particular channel.

Let Split Coefficients S_{16} and S_{11} indicate the amount of data traffic sent over the WiMAX and WiFi channels, respectively. It is seen that [1],

$$S11 + S16 = 1 \qquad (1)$$

Our analysis deals with the effect of S16 and S11 on throughput as data traffic is transferred from one radio channel to the other.

Let A(f) be the total data to be transmitted for a flow f, then the actual data that being transmitted over WiMAX and WiFi channels is given by,

$$A16(f) = A(f) * S16 \qquad (2)$$
$$A11(f) = A(f) * S11 \qquad (3)$$

Throughput and end-to-end delay is described in terms of the Split Coefficients.

$$ETT(f) = max(TD16,TD11) \qquad (4)$$
$$Reff = A(f) / ETT(f) \qquad (5)$$

Here, A(f) is the total data traffic to be transmitted through the network.

V. Description of Network Model

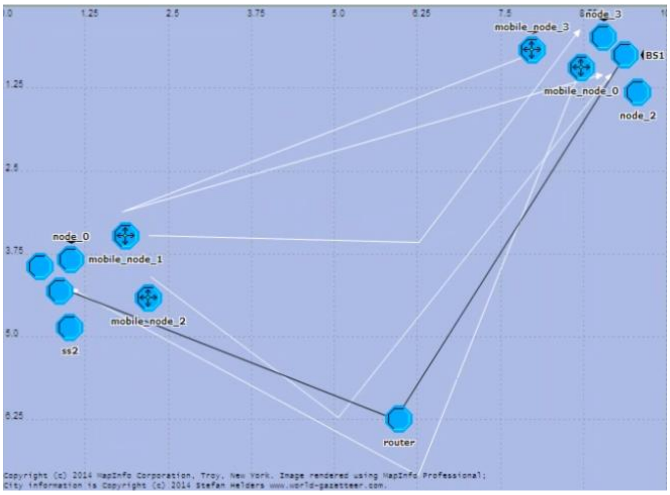

Fig.1. Network scenario for Simulation Run.

The network model represents the physical organisation of the components of the network, namely router, base stations andsubscriber stations. The base station is hard linked to the router while the subscriber stations have wireless connections to the base stations. Each subscriber stations is registered to the nearest base station. In this figure shown above subscriber stations 0,1 and 2 are connected to base station 0 and subscriber stations 2 and 3 are connected to base station 1.

VI. Description of Node Model

Node Model of Router

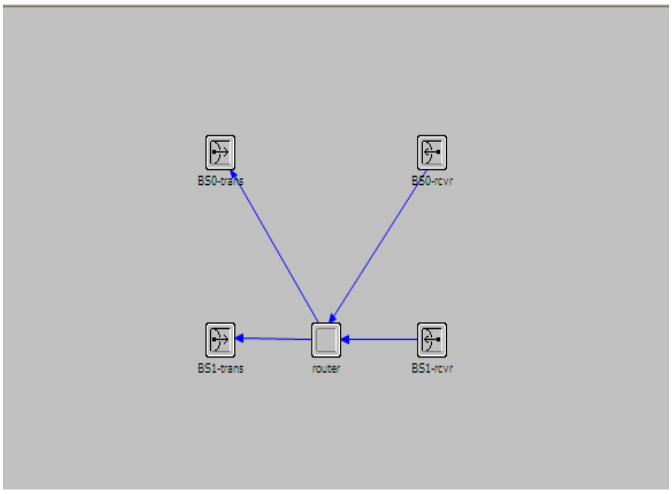

Fig 2. Node Model of Router

The router keeps track of all the base stations and its registered subscriber stations. It maintains a data structure that contains information about each subscriber station in the network and the base stations to which it is connected. During registration, it checks, if an entry is present for each subscriber station in its data structure. If it is not, then it inserts a new entry for the unregistered subscriber station.

On arrival of a packet from a base station, it retrieves the destination address from the packet performs a look-up for the base station having the destination subscriber station in its range and transmits it to the base station.

Node model of Base Station

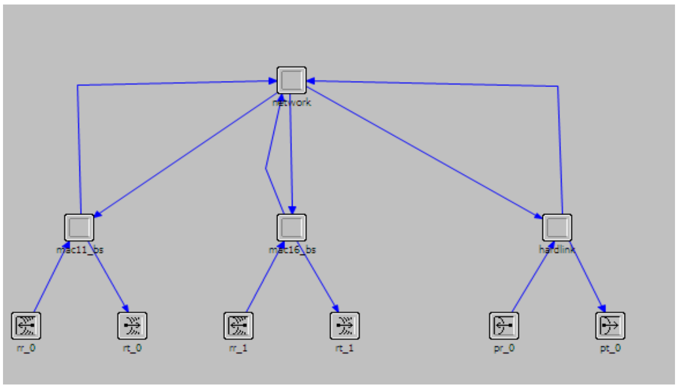

Fig 3. Node model of Base Station

The Network layer handles packets arriving from the subscriber stations and the router. Packets from the hardlink are routed to the two mac radios and vice versa.

The mac1(WiFi) and mac16(WiMax) layers have similar functionalities.

It generates initial CTS packets for discovering the subscriber stations in its range.

On receiving a packet from the lower layer, it checks the type of packet.

- If it is a NODATA PACKET, the base station checks if it has received packets from the router to be sent to the destination subscriber station. If it has, it transmits those packets and generates the next CTS.

- If it is a data packet and if it is from one of the registered subscribers, then send it to the higher layer; else destroy it.

On receiving a packet from the network layer, it inserts it into the queue of packets waiting for transmission to the destination subscriber station.

Node model of Subscriber Station

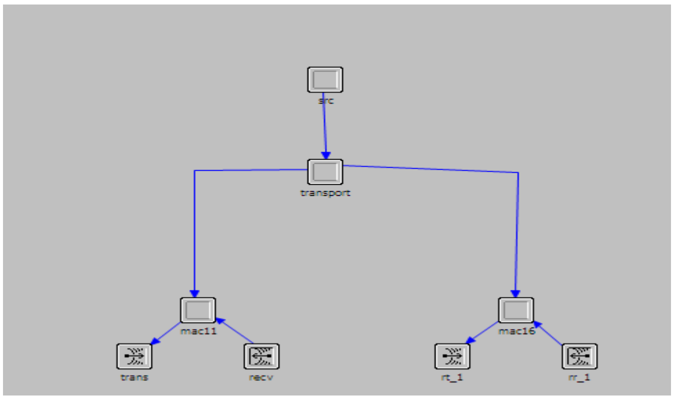

Fig 4. Node model of Subscriber Station

The Source generator generates data packets of the specified format and sends it to the lower layers to be transmitted.

The Transport layer is responsible for the actual splitting of data. For each data packet transmitted, an index number variable is incremented. Based on the index number and the specified split, the packets are either sent via WIFI or WiMax channels.

The mac1(WiFi) and mac16(WiMax) layers have similar functionalities.

One of the major functionality in this layer facilitates the registration process. It sends initial packets that allow both the base station and router to register the subscriber stations.

The layers also handle packets arriving from both the network layer and physical layer.

On receiving the packet from lower layer, it checks the type of the packet.

- If it is a CTS packet, it sends to the higher layers indicating it to transmit its data to its registered base station.
- If it is a data packet, it checks the destination address. If it is its own mac address, it sends it to the higher layers for further processing else destroys it.

On receiving a packet from higher layer, it queues the packets in a list for transmission and waits for the arrival of CTS.

While transmitting, it accesses the list of queued packets and sends the packets to the transmitter.

VII. DESCRIPTION OF PROCESS MODEL

Process models of Router

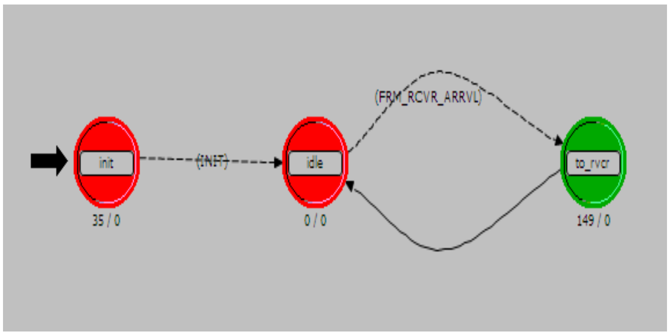

Fig 5. Router – Network Layer Process Model

Init state

This state is entered on arrival of the begin simulation interrupt. It performs necessary initializations and enters the idle state where it waits for arrival of other interrupts. Here, a table with key as the mac address and value as the out stream for packets to be forwarded is created and initialized.

To_rcvr state

This state is entered on arrival of a packet from any of the streams connected to its node model. . If a packet is arriving for the first time through a stream, it is considered as registration packet which populates the table. After registration, all other packets are forwarded to the corresponding out streams for routing purpose.

Process models of Base Station

Network layer

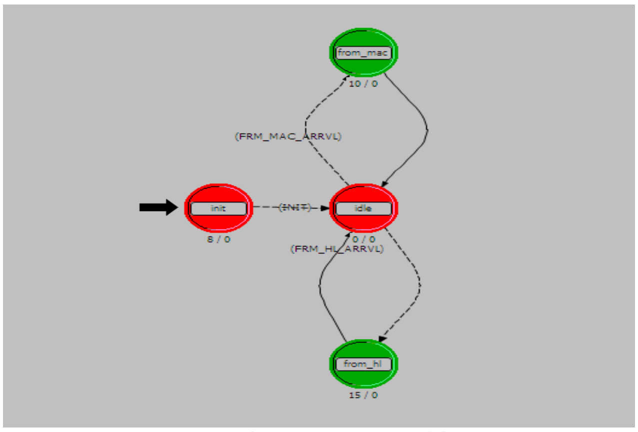

Fig 6. Base Station – Network Layer Process Model

Init state

This state is entered on arrival of the begin simulation interrupt. It performs necessary initializations and enters the idle state where it waits for arrival of other interrupts.

From_mac state

This state is entered on arrival of a packet from the mac layer. It sets the statistics of the number of packets sent to the router and sends the packets to the higher layer.

From_hl state

This state is entered on arrival of a packet from the hard link from the router. It sets the statistics of the number of packets received from the router and sends the packets to the lower layer.

Mac11 BS Process Model - Wi-Fi Mac Layer

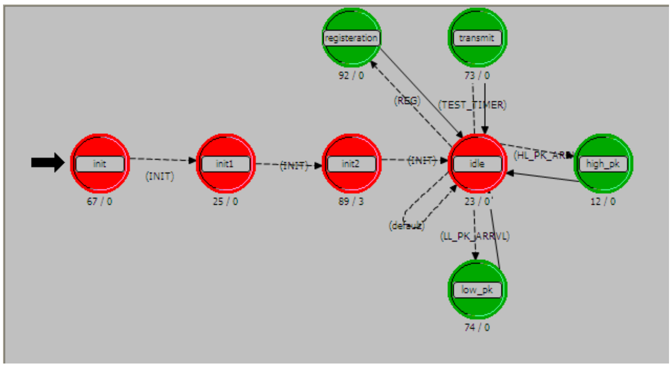

Fig 7. Base Station – Mac11 Process Model

Init state

In this state, a unique MacAddresss is assigned for each node in the network. It identifies the subscriber stations that are within a specified range and inserts them into the nodeList.

Idle state

This is the default state; it stays in this state in the absence of any interrupt. Before sending CTS packet to a subscriber station, this state checks if there are packets that have arrived from the hard link and are waiting to be delivered to the subscriber stations. If so, it generates an interrupt to enter the transmit state. Else, it generates the next CTS allowing the next subscriber station to transmit its data.

Lowpk state

This state is entered when an interrupt occurs indicating the arrival of a packet from a lower layer(receiver). The arriving packets can be of 2 types: DataPacket and NoDataPacket. In this state the packet format is checked.

If it is a 'DataPacket', it checks if the packet is intended to itself. If so, it sends it to the higher layer (network). If not, it destroys the packet.

If it is a 'NoDataPacket', it signals for the generation of the next CTS.

Highpk state

This state is entered when an interrupt occurs indicating the arrival of a packet from a upper layer(network layer). The arriving packets can be of Data Packet type. These packets have been received by the base station through the hard link from the router. These packets are queued up in the FrmHLList for transmission to the destination subscriber station.

Mac16 BS Process Model - Wi-Max Mac Layer

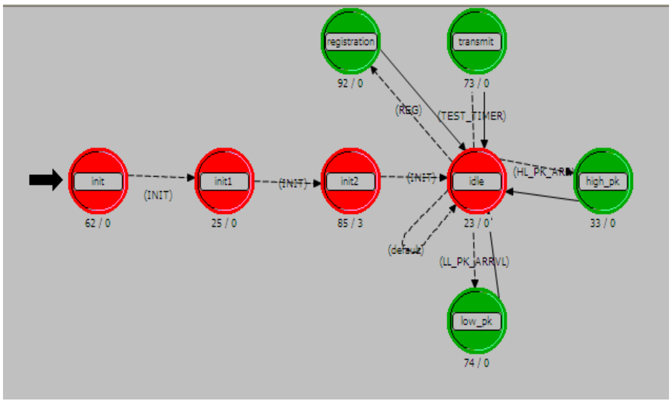

Fig 8. Base Station – Mac16 Process Model

This model is similar in functionality to the above model, Mac11 model. It is different in the aspect that it has separate radio transmitter and receiver, which have different data rate and ranges compared to Wi-Fi radio transmitter and receivers.

Process models of subscriber station

Generate state

This process state generates packets of a specified format, here the format being DataPacket. It starts generating packets at the start of simulation and goes up till infinity. The packets get generated at a constant inter-arrival time and are sent to the lower layer, here transport layer.

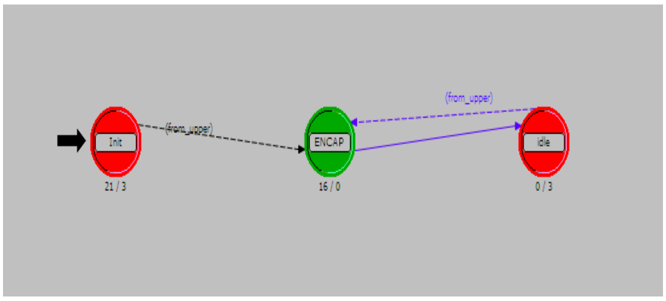

Fig 9. Subscriber Station – Transport Process Model

Transport Process Model

Fig. 9 shows the transport layer process model of the subscriber station that is responsible for splitting of data traffic.

Encap state

This state splits the DataPackets that are received from the source. The split ratio is mentioned in the init state. According to the split ratio, the packets are sent to Wi-Fi or WiMax Mac Layer. For example, for every 10 packets, if split ratio mentioned is 3, then the first 3 packets are sent to Mac layer of Wi-Fi and rest 7 are sent to Mac layer of WiMax.

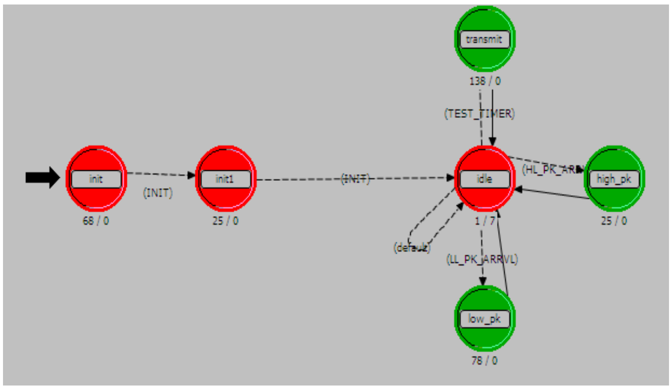

Fig 10. Subscriber Station – Mac11 Process Model

Init state

In this state, a unique Mac Addresss is assigned for each node in the network.

Idle state

This is the default state; it stays in this state in the absence of any interrupt.

Lowpk state

This state is entered when an interrupt occurs indicating the arrival of a packet from a lower layer (receiver). The arriving packets can be of 2 types: CTSToSS and DataPacket. In this state the packet format is checked.

If it is a 'CTSToSS' packet, it checks if the packet is intended to itself. If it is, it calls an interrupt to enter into transmit state for transmission of DataPackets. If not, it destroys the packet with no further action.

If the arriving packet is a DataPacket, it sets the statistics for number of packets received and destroys the packet.

Highpk state

This state is entered when an interrupt occurs indicating the arrival of a DataPacket from a upper layer (transport). It then puts the packet into the waiting packet list, where is waits for transmission.

Transmit state

This state is entered on receiving an interrupt from lowpk. If the interrupt is caused due to the first CTS, then it sends a single DataPacket for the purpose of registration. If not, on arrival of a CTS, it retrieves DataPackets from the waiting packet list and sends at most 20 packets to the transmitter for transmission. It signals the end of data transmission by sending a NoDataPacket.

Mac16 SS Process Model – Wi-Max Mac Layer

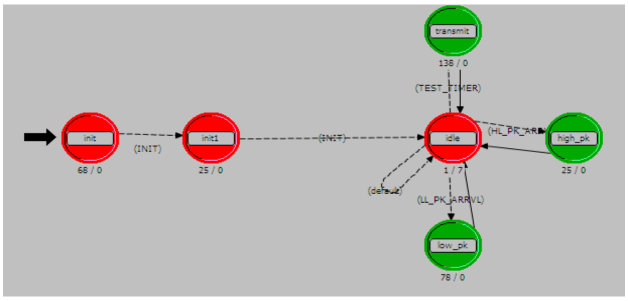

Fig 11. Subscriber Station – Mac16 Process Model

This model is similar in functionality to the above model, Mac11 model. It is different in the aspect that it has separate radio transmitter and receiver, which have different data rate and ranges compared to Wi-Fi radio transmitter and receivers.

VIII. Simulation Results and Analysis

In this section, we describe the simulation setup and our analysis. The simulation is performed on OPNET Modeler. The simulation network is shown in Figure 1. The range of WiMAX and WiFi radios differ greatly. Also, the data rates at which WiFI and WiMax radios operate are considerably different.

Hence to consider the different conditions under which a network might work, simulations are run for different combinations of these parameters. In addition,for each combination of the parameters, the network is simulated for different Split Coefficients.

The splitting decision is statically made at the “transport” layer with regard to data packets arriving from the higher layers. The pseudo code for this splitting decision is shown in Fig. 12 below:

```
PSEUDO-CODE FOR TRAFFIC SPLITTING:

Split Coefficient = K        (0 ≤ K ≤ 10)
        Packet Count = i = 0
    Receive Packet i from higher layers:

            if j < K:
        transmit packet to WiFi Section
                else:
        transmit packet to WiMax Section
                  i=i+1
i = i mod(10)
```

Fig. 12 Pseudo Code for the Traffic splitting section

Initially, simulations were run for a network with only static nodes. The network consists of a router, base stations and stationary subscriber stations.

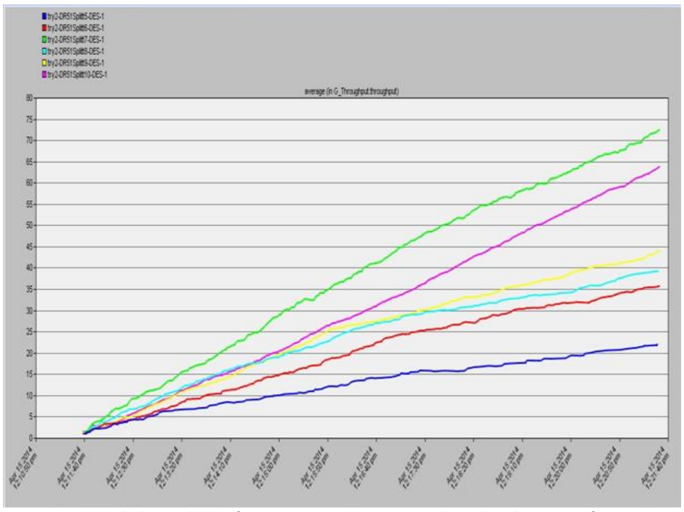

Fig. 13 Global throughput for various split ratios when the data rate for Wi-Fi and Wi-Max are in the ratio 5:1

The simulations showed that the network performed best for a split ratio of 7. This is observed because with a split Coefficient of 7, 7 data packets out of 10 are sent through the WiFi radio which has a higher data rate than that of WiMax.

Simulations performed for a network with mobile nodes showed similar results. The network consisted of a router, base stations, stationary and as well as mobile subscriber nodes.

The graphs in Figss 13-17, show the results of the simulation for various scenarios of the network. The plots consist of a graphs showing Throughput Vs Time. Each graph is plotted for a simulation of the network under different combinations of data rates and ranges for different Split Coefficients as shown in Table I.

TABLE I

Simulation Runs	Radio	Range	Data Rate
Run 1	IEEE802.16/ WiMAX IEEE802.11/WiFi	1Km 100mts	1Kbps 5Kbps
Run 2	IEEE802.16/ WiMAX IEEE802.11/WiFi	3Kms 1Kms	1Kbps 2Kbps
Run 3	IEEE802.16/ WiMAX IEEE802.11/WiFi	2Km 1Km	1Kbps 5Kbps
Run 4	IEEE802.16/ WiMAX IEEE802.11/WiFi	8 Km 1 Km	1 Kbps 2 Kbps

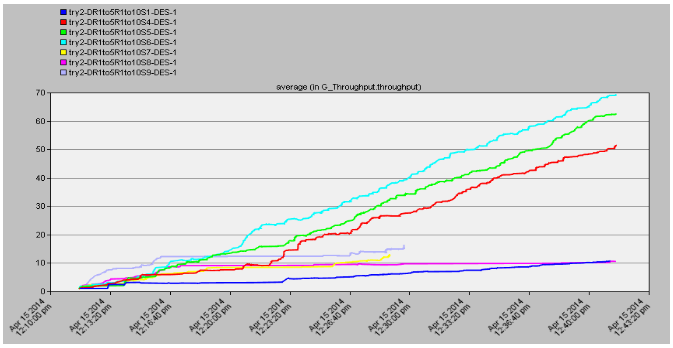

Fig. 14 Throughput(bps) Vs Time for Simulation run 1

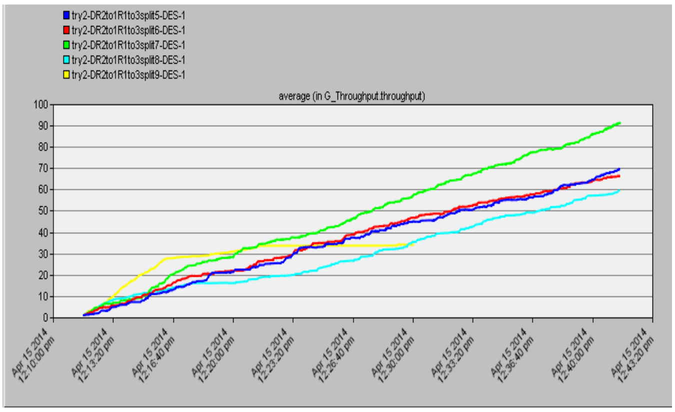

Fig. 15 Throughput(bps) Vs Time for Simulation run 2

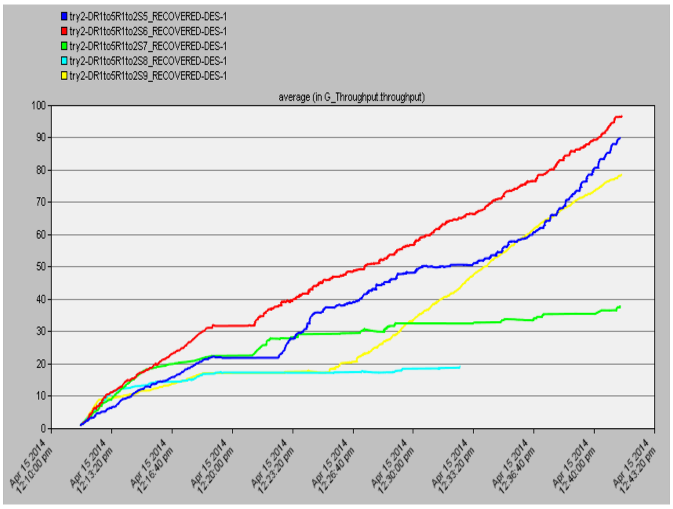

Fig. 16 Throughput(bps) Vs Time for Simulation run 3

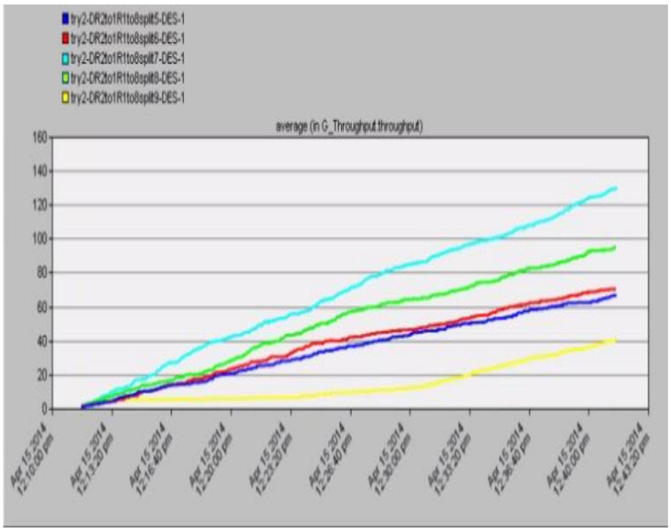

Fig. 17 Throughput(bps) Vs Time for Simulation run 4

It has been observed from the graphs that for all combinations of ranges and data rates, performance of the network in terms of bits per second is best when the split Coefficient is in the range of 6 to 7. The throughput of the network is observed to be in the range of 90 – 120, for the Split Coefficient at which the network has best performance in each scenario.

Another observation made from the graphs is that the throughput for Split Coefficients beyond 7 decreases in every scenario. This is because, at higher Split Coefficients, majority of the data packets are transmitted through WiFi data streams.

As a result, the higher range available in WiMax is not efficiently used by the network during communication. Subscriber stations accessible to the base station through the WiMax radio are considered inaccessible for transmission of packets routed through WiFi, hence adding to the delay.

IX. CONCLUSION

In this paper we have discussed a mechanism for traffic splitting in an infrastructure network based on the PCF. From the mechanism presented we have seen that traffic splitting improves throughput of the overall network compared to the throughput of the network when no traffic splitting is involved which occurs at a split coefficient value of 1 or 0.

In future works, we would like to do a specific study of backend features of Wifi, Wimax, 3G and LTE networks and bring them into the purview of our research. Another interesting area of future research is the spontaneous creation of Ad-hoc network between a node that has access to only another subscriber which might be connected to the base station.

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Kiran K was born in India on June 9, 1978. He obtained his B.E and M.E degrees in Computer Science and Engineering from Bangalore University, Bangalore. Presently he is pursuing his Ph.D in Bangalore University.
He is currently working as an Assistant Professor and pursuing his Ph.D in the Department of Computer Science and Engineering at University Visvesvaraya College of Engineering, Bangalore. His areas of interest include Wireless Networks, Distributed Systems, Design and Analysis of Algorithms, and File Structures.

Lakshmi B S has completed her Bachelor of Enginering in Computer Science and Engineering from University Visvesvaraya College of Engineering, Bangalore. She has been an active member of IEEE for 3 years. Her areas of interest include computer networks and operating systems.

Priyanka Negi has completed her Bachelor of Enginering in Computer Science and Engineering from University Visvesvaraya College of Engineering, Bangalore.. Her areas of interest include Computer Networks Data Structures and Data Analytics.

Ramitha Manjunath has completed her Bachelor of Engineering in Computer Science and Engineering from University Visvesvaraya College of Engineering, Bangalore. She has been an active IEEE member since 4 years and her areas of interest include Computer Networks and Data Analytics.

Shrughy S has completed her Bachelor of Engineering in Computer Science and Engineering from University Visvesvaraya College of Engineering, Bangalore. She has been an active IEEE member since 4 years and her areas of interest include Data Mining and Computer Networks.

Dr P Deepa Shenoy is currently working as a professor in the Department of Computer Science and Engineering, University Visvesvaraya College of Engineering, Bangalore. She did her doctorate in the area of Data Mining from Bangalore University in the year 2005. Her areas of research include data mining, soft computing, biometrics and social media analysis. She has published more than 100 papers in refereed International conferences and journals. She is also a senior member of IEEE and currently serving as student activity chair, IEEE Bangalore section.

K R Venugopal is currently the Principal, University Visvesvaraya College of Engineering, Bangalore University, Bangalore. He obtained his Bachelor of Engineering from University Visvesvaraya College of Engineering. He received his Masters degree in Computer Science and Automation from Indian Institute of Science Bangalore. He was awarded Ph.D. in Economics from Bangalore University and Ph.D. in Computer Science from Indian Institute of Technology, Madras. He has authored and edited 39 books on Computer Science and Economics and has published over 400 research papers. His research interests includes Computer Networks, Wireless Sensor Networks, Parallel and Distributed Systems, Digital Signal Processing and Data Mining.

L M Patnaik is currently Honorary Professor, Indian Institute of Science, Bangalore, India. He was a Vice Chancellor, Defence Institute of Advanced Technology, Pune, India and was a Professor since 1986 with the Department of Computer Science and Automation, Indian Institute of Science, Bangalore. During the past 35 years of his service at the Institute he has over 700 research publications in refereed International Journals and refereed International Conference Proceedings. His area of research interest includes Parallel and Distributed Computing, Mobile Computing, CAD for VLSI circuits, Soft Computing and Computational Neuroscience. He is a Fellow of all the four leading Science and Engineering Academies in India; Fellow of the IEEE and the Academy of Science for the developing World. He has received twenty national and international awards; notable among them is the IEEE Technical Achievement Award for his significant contributions to High Performance Computing and Soft Computing.