Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**4IPP Traffic Model for IEEE 802.16.3**
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Re:	This contribution is in response to the 802.16.3 Task Group Call for Contributions: Session #10, Topic: Traffic, Deployment and Channel Models, IEEE-802.16-00/13, 2000-9-15
Abstract	The contribution defines a general traffic model which provides typical self-similar traffic for a point-to-multipoint fixed wireless WAN applications. The model accurate characterizes measured traffic for both Ethernet and Internet traffic. The contribution defines the traffic model for various proto-typical cases. It also provides a definition of what MAC/PHY performance metrics to calculate as a means of characterizing the performance of the MAC/PHY.
Purpose	The contribution describes a traffic model to be used for characterizing performance of MAC/PHY proposals for consideration as components of the common air interface standard for IEEE 802.16.3.
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4IPP Traffic Model for IEEE 802.16.3

C. R. Baugh, Ph.D.

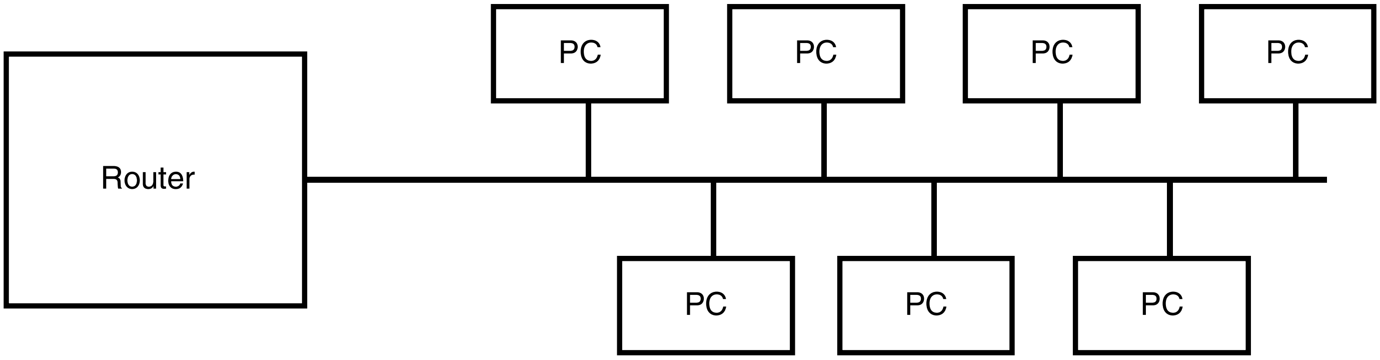
1 Introduction

This contribution defines a traffic model that generates traffic for a point-to-multipoint, fixed-wireless WAN. The traffic model generates self-similar traffic found in Ethernets and on the Internet. The model has been proven to accurately predict measured traffic for both Ethernet and Internet traffic. The model generates traffic in one direction of flow only. To obtain a two-way traffic flow a summation of two independent models is necessary. The summation of the two one-way models can represent both symmetric and asymmetric traffic with respect to the forward and reverse directions from the central point-to-multipoint hubs to individual and remote subscribers.

The contribution contains the following three major sections:

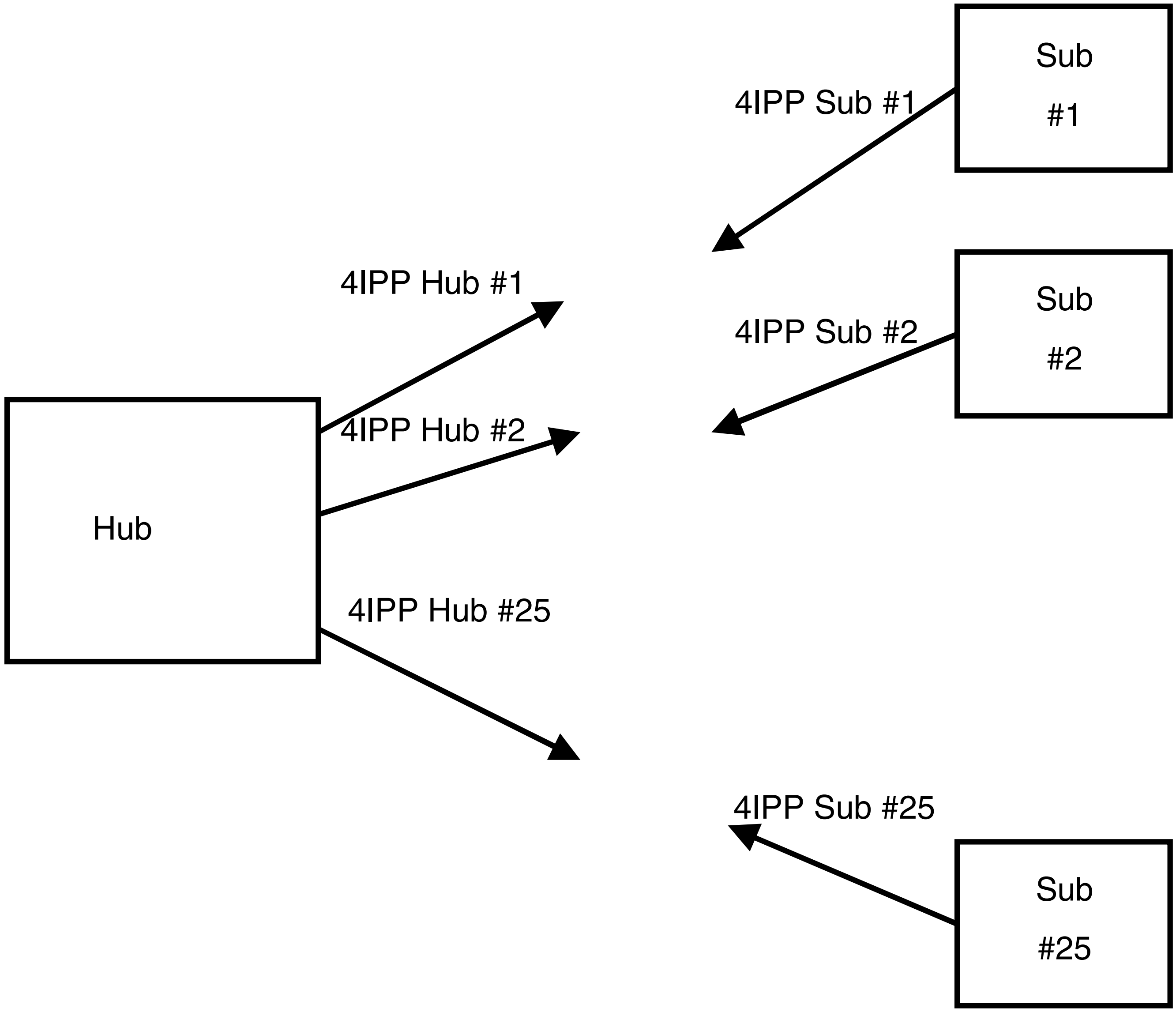
- A model for generating one-way traffic for a single subscriber unit's WAN traffic to or from the point-to-multipoint hub
- A description of proposed set of WAN traffic scenarios for characterizing the performance of a common air interface proposal under different traffic conditions
- A set of parameters to calculate when using the model for characterizing the performance of a candidate MAC/PHY air interface when using the proposed traffic scenarios

The model simulates the traffic associated with the link between the LAN and a Router as shown in the following figure. The model does NOT simulate the traffic that stays on the LAN which does not exit the LAN to the router. To simulate the traffic destined for the router from the LAN, the model has an "on" time when it is generating packets to the router and it has an "off" time when the packets are going from one device on the LAN to another device on that same LAN segment. Since the model only simulates one direction of the traffic, a second simulation model is required for the traffic coming from the router to the LAN.



The traffic in the above figure simulates the traffic to and from the point-to-multipoint hub and the remote subscriber unit as the router represents the hub and the LAN represents the subscriber unit.

To generate the traffic for a set of subscriber units all sharing a common point-to-multipoint hubs, each subscriber unit would need a pair of traffic generation models. One model for the forward traffic to the subscriber and another for the reverse traffic from the subscriber unit. Thus, for a set of 25 subscriber units serviced by a single hub, the traffic generation model consists of the summation of 25 pairs (forward/reverse) of traffic generators. The following figure shows the traffic flows over a common point-to-multipoint hub with 25 subscribers.



2 Description of the Model

The model is based on an Interrupted Poisson Process (IPP). To generate the self-similar traffic a superposition of 4IPPs has been found to be a good model to use. See reference 1 [Andersen] for details. Each Interrupted Poisson Process generates traffic between the hub and the subscriber unit.

2.1 Application of the 4IPP model to fixed, wireless, point-to-multipoint WANs

The model is a superposition of four Interrupted Poisson Process (4IPP) in which each IPP spans a distinct time frame in order to generate the self-similar traffic found in Ethernet and Internet traffic. The following figure defines each of the normalized Interrupted Poisson Processes. The Interrupted Poisson Process has two states – ON and OFF. During the ON state, the Interrupted Poisson Process generates λ packets/unit-of-time. During the OFF state, the Interrupted Poisson Process does not generate packets. The transition probability rate, c1, is the number of transitions from the ON state to the OFF state per unit-of-time. The transition probability rate (1-c1) is the number of transitions from the ON state to the ON state per unit-of-time. The transition probability rate, c2, is the number of transitions from the OFF state to the ON state per unit-of-time. The mean dwell or "sojourn" time in state 1 (ON time) is 1/c1 (unit-of-time), and the mean dwell time in state 2 (OFF time) is 1/c2 (unit-of-time). The long-term mean probability of being in the ON state is c2/(c1 + c2), and for the OFF state is c1/(c1 + c2). . Thus, the parameters c1, c2 and λ characterize the Interrupted Poisson Process.

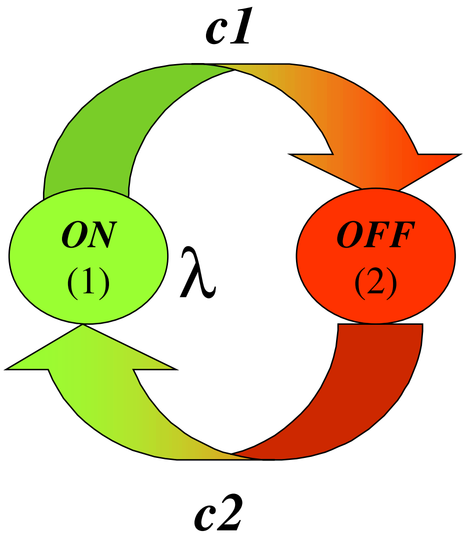
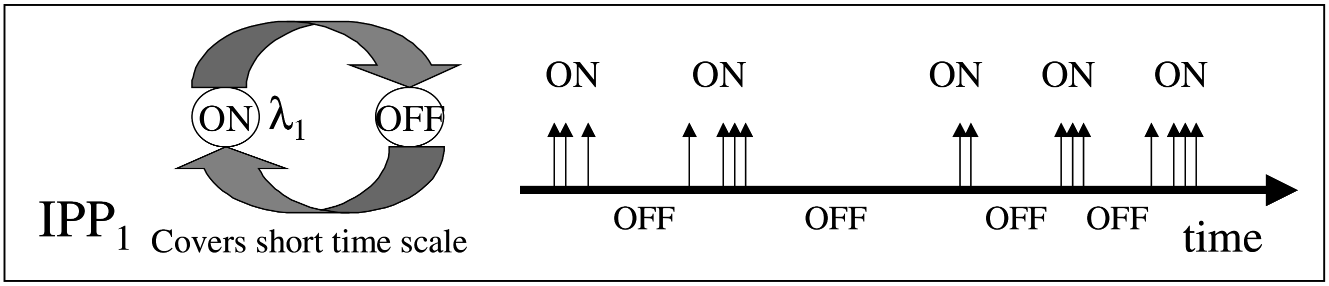


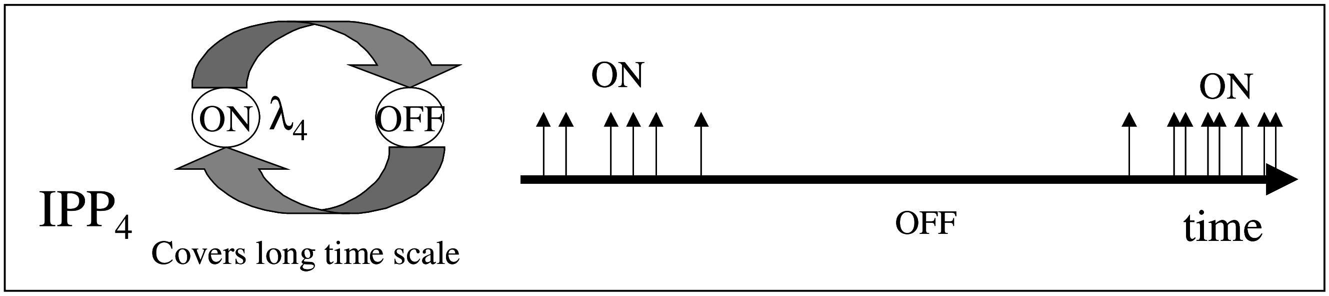
Figure 2-1: Normalized IPP Model

The normalization factor in the IPP model in Figure 2-1 is that transition probability rates are scaled such that the transition probability rates emanating from any one state sum to 1, i.e. c1 + (1-c1) = 1. When the IPP model is used (as will be seen in a later section), the transition probability rates will be scaled from normalized "unit-of-time" to seconds to realize a given data rate and packet size (e.g. 4 Mbps and 192-byte-packets of simulated subscriber LAN traffic).

To model the self-similar traffic found in Ethernet and Internet traffic samples, four Interrupted Poisson Processes are superimposed. Each of the four processes has different c1, c2 and λ parameters to represent 4 different time scales found in the self-similar traffic. The following figures graphically demonstrate these different time scales that are represented by the different values of c1, c2 and λ. The packet traffic is reasonably well modeled by using just 4 Interrupted Poisson Processes if the parameters of each Interrupted Poisson Process are appropriately chosen.



The above figure shows the packets being generated over a short time scale. The following figure shows the packets being clustered at a longer time scales. The 4IPP model superimposes 4 different time scales to generate an accurate



representation of traffic for Ethernet and Internet.

2.2 Basic assumptions of the model

The basic model assumes the following construction of traffic between each fixed subscriber unit and the central point-to-multipoint hub. The subscriber unit uses a 4IPP model to determine the traffic the subscriber unit sends to the hub. The hub uses a 4IPP model to determine the traffic the hub sends to that same subscriber unit. Thus, a point-to-multipoint hub with 25 subscribers has 25 4IPP generators for the traffic to the subscriber units (forward) and another 25 4IPP generators for the traffic to the hub (reverse).

The model also assumes that the traffic from both the hub and the subscriber unit originates from a LAN that connects to the subscriber unit or the hub. In the case of the subscriber unit the subscriber unit is assumed to connect to a router on the subscriber premises LAN. On the hub side, the traffic arriving at the hub from the packet data network is assumed to originate from some server farm that has a LAN that connects to the router that routes the traffic to this hub. In either case, it is assumed that only a small fraction of the traffic (e.g. approximately 10% if symmetric traffic is assumed) goes over the air interface from these LANs with the remainder of the LAN traffic remaining local to that LAN.

Another assumption of the model is the fact that the maximum average Ethernet traffic or average throughput is about 40% of the LAN maximum capacity. Hence, a 10 Mbps Ethernet handles 4 Mbps of average traffic as its maximum average traffic. For the symmetric traffic case, the model assumes both directions of the traffic originate from a 10 Mbps LAN operating at an average 4 Mbps in which the average data rate is the same in both forward and reverse directions.

The scaling of the model parameters involves two steps. First, an intermediate set of 4IPP parameters is derived for internal LAN traffic reflecting a 40% ON state [time ratio of ON/(ON+OFF)] commensurate with 4 Mbps/10 Mbps. The second step recognizes that only about 10% of the internal LAN traffic exits the LAN as external traffic, flowing over the air interface of the point-to-multipoint radio system. This leads to an external traffic 4IPP model that is ON about 4% of the time (one-tenth that of the hypothetical internal traffic model construct). As stated above, for symmetric traffic, this model is used for each direction of traffic to/from a subscriber unit (two models for each subscriber unit).

For a 10:1 ratio of forward-to-reverse asymmetric case (which can be a reasonable model for individuals at the subscriber premises primarily accessing the web), we start with the assumption that the hub traffic to the subscriber unit is the same as the model described above; i.e., a 10 Mbps LAN with 40% peak load (4 Mbps) bursting packets to that subscriber 4% of the time, or 400 kbps in the forward direction. However, in keeping with the 10:1 asymmetry premise, the subscriber unit would only be sending external traffic packets in the reverse direction at a rate of 40 kbps. If it is assumed that the subscriber also has a 10 Mbps LAN with 4 Mbps average internal LAN traffic (like the hub forward traffic to this subscriber), then this 10:1 asymmetry premise means that the external reverse traffic model at the subscriber unit is ON only about 0.4% of the time.

For a 4:1 ratio of forward-to-reverse traffic, the hub model would assume, as before, a 10 Mbps LAN operating at 40% peak load (4 Mbps average data rate) having only 10% of the traffic exiting the LAN towards the subscriber unit (ON about 4% of the time). The reverse channel subscriber unit traffic model would send packets to the hub only about 1% of the time.

For all of the symmetric and asymmetric scenarios described above, a fundamental assumption about the nature of the internal “10 Mbps LAN” traffic at both ends of the air interface has been kept constant to preserve the high-speed packet characteristics in both directions of traffic flow. Only the time ratios of ON/(OFF+ON) have been adjusted to equivalently “divert” shorter- or longer-windowed bursts of external traffic, depending on the desired (a)symmetry.

The parameters that define these models for a set of subscribers will be described in a later section of this contribution.

3 Description of the traffic simulation model

3.1 Basic 4IPP parametric model.

The parameters in the following table define the basic 4IPP model. These parameters are chosen to match self-similar traffic that has a Hurst parameter of 0.9. The Hurst parameter is the measure of correlation of the present packet with the previous packet. The Hurst parameter of 0.9 matches the traffic measure at both Telcordia Technologies and at the Lawrence Berkeley Labs. The parameters were derived from reference 1 [Andersen].

Each row of the table describes one of the four IPPs. The second column contains the λ value for the average packets per unit of time. The third column contains parameter c1 that determines the transition probability rate of going from the ON state (bursting packets over the air link) to the OFF state. Column three contains the parameter c2 that determines the transition probability rate of going from the OFF state (packets stay within the LAN and do not go over the air interface) to the ON state. The last column contains the total average packets for the sum of the ON and OFF times. The last row of the last column contains the average packet rate per unit of time for the superposition of all 4 IPPs combined.

The parameters of the model are shown in Figure 3-1 below

source_i	**λi IPP in ON state (pkts/unit-of-time)**	**c1i (transition probability rate from ON to OFF) transitions/ unit-of-time**	**c2i (transition probability rate from OFF to ON) transitions/ unit-of-time**	***Averaged over both ON and OFF states (pkts/unit-of-time)***
IPP#1	***2.679***	**4.571E-01**	**3.429E-01**	*1.1480*
IPP#2	***1.698***	**1.445E-02**	**1.084E-02**	*.7278*
IPP#3	***1.388***	**4.571E-04**	**3.429E-04**	*.5949*
IPP#4	***1.234***	**4.571E-06**	**3.429E-06**	*.5289*
			4IPP Average Rate (pkts/unit-of-time) =	***3.00***

Figure 3-1: Basic 4IPP Model

3.2 Scaling of the model: internal vs. external traffic

The 4IPP model of the previous section must be scaled to give the appropriate data rate for the test cases stated in a following section of the contribution. For example, the model must be scaled, as an intermediate step, to generate a 4 Mbps data rate for internal LAN traffic. From the Telcordia and Lawrence Berkeley Labs data, the average packet size is 192 bytes or 1536 bits. Thus, the packets per second for a 4 Mbps data rate is 4,000,000/1536 = 2604 packets per sec. All of the parameters of the basic model in Figure 3-1 must be scaled by:

2604 packets per sec / 3 packets per unit-of-time = 868 unit-of-time per sec

to insure the average packets/sec becomes 2604 for the superposition of all 4IPPs.

The 4 Mbps 4 IPP internal LAN traffic model (intermediate step) then becomes as shown in Figure 3-2.

source_i	λ_i IPP in ON state (pkts/sec)	c1i (transition probability rate from ON to OFF) transitions/ sec	c2i (transition probability rate from OFF to ON) transitions/ sec	*Averaged over both ON and OFF states (pkts/sec)*
IPP#1	*2326*	3.968E+02	2.977E+02	996.8
IPP#2	*1474*	1.254E+01	9.410E+00	631.8
IPP#3	*1205*	3.968E-01	2.977E-01	516.4
IPP#4	*1071*	3.968E-03	2.977E-03	459.1
			4IPP Average Rate (pkts/sec) =	*2604*

Figure 3-2: 4 Mbps 4IPP Model

Then the internal LAN traffic model must be scaled appropriately to model external traffic, which is a fraction of the 4 Mbps internal LAN traffic. This modeling step can be thought of as using a time-window to divert a portion of the internal traffic as external traffic. Scaling the ON/(ON+OFF) time by the desired factor results in time-windowed bursts of packets. This preserves the high-rate nature of the traffic while a burst is "ON" but scales down the overall average load by shortening the average burst duration (see reference 3 [Leland and Wilson]). The ON time should be decreased while the OFF time is increased by the same amount in order to preserve the average duration of the overall ON-OFF period. For external traffic of 400 kbps, the ON time is reduced by a factor of 10 from the 4 Mbps ON time. Similarly, for external traffic loads of 40 kbps or 100 kbps, the ON time is reduced by a factor of 100 or 40, respectively, from the 4 Mbps ON time. Asymmetric traffic loads can then be modeled using an X kbps external traffic model in the forward direction and a Y kbps external traffic model in the reverse direction for each subscriber unit.

The 4 IPP model for 400 kbps external traffic then becomes as shown in Figure 3-3 below when the ON time window is scaled down by a factor of 10 from the 4 Mbps internal traffic model.

source_i	λ_i IPP in ON state (pkts/sec)	c1i (transition probability rate from ON to OFF) transitions/ sec	c2i (transition probability rate from OFF to ON) transitions/ sec	*Averaged over both ON and OFF states (pkts/sec)*
IPP#1	*2326*	*3.968E+03*	*1.777E+02*	99.68
IPP#2	*1474*	*1.254E+02*	*5.617E+00*	63.18
IPP#3	*1205*	*3.968E+00*	*1.777E-01*	51.64
IPP#4	*1071*	*3.968E-02*	*1.777E-03*	45.91
			4IPP Average Rate (pkts/sec) =	*260*

Figure 3-3: 400 kbps External Traffic 4IPP Model

The 4IPP model for 100 kbps external traffic then becomes as shown in Figure 3-4 below when the ON time window is scaled down by a factor of 40 from the 4 Mbps internal traffic model.

source_i	**λi IPP in ON state (pkts/sec)**	**c1i (transition probability rate from ON to OFF) transitions/ sec**	**c2i (transition probability rate from OFF to ON) transitions/ sec**	***Averaged over both ON and OFF states (pkts/sec)***
IPP#1	***2326***	***1.587E+04***	***1.719E+02***	24.92
IPP#2	***1474***	***5.017E+02***	***5.435E+00***	15.79
IPP#3	***1205***	***1.587E+01***	***1.719E-01***	12.91
IPP#4	***1071***	***1.587E-01***	***1.719E-03***	11.48
			4IPP Average Rate (pkts/sec) =	***65***

Figure 3-4: 100 kbps External Traffic 4IPP Model

These would be the values for 40 kbps External Traffic 4IPP Model

source_i	**λi IPP in ON state (pkts/sec)**	**c1i (transition probability rate from ON to OFF) transitions/ sec**	**c2i (transition probability rate from OFF to ON) transitions/ sec**	***Averaged over both ON and OFF states (pkts/sec)***
IPP#1	***2326***	***3.968E+04***	***1.708E+02***	9.968
IPP#2	***1474***	***1.254E+03***	***5.400E+00***	6.318
IPP#3	***1205***	***3.968E+01***	***1.708E-01***	5.164
IPP#4	***1071***	***3.968E-01***	***1.708E-03***	4.591
			4IPP Average Rate (pkts/sec) =	***26***

Figure 3-5: 40 kbps External Traffic 4IPP Model

4 System test scenarios

The traffic model generates the test cases for characterizing the PHY/MAC behavior. The following test cases establish the test scenarios for a single radio link from a point-to-multipoint hub to multiple remote subscriber units. The test scenarios do not cover the case in which there is a cellular like network of multiple hubs reusing the same carrier frequencies or the case of a single hub with multiple sectors in which some of the sectors may be reusing the same carrier frequencies. The simulations for such networking scenarios may be too complex and too computationally intensive.

The test cases consist of three different traffic models as shown in the following table where the traffic has a 10:1 asymmetric ratio in the first case, and 4:1 asymmetric ratio in the second case and a symmetric traffic of ratio 1:1 in the third case. For each test scenario each subscriber has two traffic generators one for each direction of the traffic.

Test Scenario	**Forward Traffic (Hub to Sub)**		**Reverse Traffic (Sub to Hub)**	
	Data Rate	**Model**	**Data Rate**	**Model**
No. 1 - 10:1	400 kbps	Figure 3-3	40 kbps	Figure 3-5
No. 2 - 4:1	400 kbps	Figure 3-3	100 kbps	Figure 3-4
No. 3 - 1:1	400 kbps	Figure 3-3	400 kbps	Figure 3-3

4.1 Simulation results (System performance)

The simulation results establish the system performance as characterized by the number of subscribers, the mean and standard deviation of the forward and reverse traffic and the mean and standard deviation of the delay in the forward and reverse direction. To obtain the performance of a system of 20 subscribers, the simulation would have one 4IPP model for each subscriber to generate the traffic towards the hub from each of the 20 subscribers in the reverse direction. It would also have 20 4IPP models at the hub, one for generating the traffic to each subscriber in the forward direction. The traffic in the forward direction is the sum of all the 20 hub models and the traffic in the reverse direction is the sum of all 20 subscriber models.

4.1.1 Maximum number of subscribers

The maximum number of subscribers the system can support is defined in terms of the delay. Since the traffic grows as the number of subscribers grows, the mean delay increases as the number of subscriber increase. The maximum number of subscribers N is defined as the operating point at which the (N+1)th subscriber first meets the following inequality for either the forward direction or else the reverse direction:

Mean delay for N+1 subscribers > 4 x (Mean delay for N subscribers)

or the:

Mean delay > 200 msec

whichever occurs first. The choice of numbers results from a maximum mean delay (200 ms) for the radio link and for staying away from the operating point at which the delay grows very rapidly.

4.1.2 Mean and standard deviation of data rate and delay

To characterize the performance of the system, the MAC/PHY must be characterized by calculating entries in the following two tables. The two tables use the 3 test scenarios specified above. The first table shows the mean and standard deviation of the forward and reverse data rate as well as the sum of the means of the two. The table also includes the maximum number of subscribers that system can support using the criteria stated in the previous section for the specified data rates. The second table shows the mean and standard deviation of the delay in both the forward and reverse directions of traffic as well as the maximum number of subscribers for that delay.

Test Scenario	Number of Subscribers	Forward Data (bits/sec) (Hub to Sub)		Reverse Data (bits/sec) (Sub to Hub)		Sum of Means (bits/sec)
		Mean	Standard Deviation	Mean	Standard Deviation	
No. 1 - 10:1						
No. 2 - 4:1						
No. 3 - 1:1						

Table 4-1: Data Capacity of the Fixed Radio System

Test Scenario	Number of Subscribers	Forward Direction Delay (ms) (Hub to Sub)		Reverse Direction Delay (ms) (Sub to Hub)	
		Mean	Standard Deviation	Mean	Standard Deviation
No. 1 - 10:1					
No. 2 - 4:1					
No. 3 - 1:1					

Table 4-2: Delay Performance of the Fixed Radio System

5 References

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