

# A Design of a MAC layer a protocol for CBR and VBR data transmission on single channel in wireless lans

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*Abstract: This paper presents a design of a MAC Layer protocol for CBR and VBR traffic transmission on a single channel in wireless LANs (WLANs). The proposed protocol utilizes the channel spatially in a distributed manner on any partially connected networks. CBR and VBR traffics are scheduled for transmission based on the user-defined priority. The delays experienced by both the traffics are studied. The delay analysis shows that with certain startup delays and finite buffers, it is possible to schedule good number of CBR and VBR oriented applications for simultaneous transmission in WLANs.*

## 1 Introduction to Wireless LANs

Recently, wireless data communications and portable computers are increasingly becoming part of networks. Wireless networks offer the advantages like easy terminal relocatability and flexible reconfigurability of the network at minimum cost and logistics. Hence, wireless solutions are widely suggested for local area networking in office, library, factory and in-building [1, 2, 3, 4] environments.

### 1.1 CBR and VBR Traffic

According to the bit rate of the traffic two classes of traffics can be distinguished[5]; variable bit rate (VBR) traffic and constant bit rate (CBR) traffic. Characteristics of the VBR traffic are the variable data transfer delay and irregular servicing of the queues of packets waiting for transmission. VBR traffic is generated by applications such as interactive data, file transfer, electronic mail, document exchange and graphical image transfer, and by applications that require a constant end user-to-end user delay like VBR coded video, voice and HDTV. A CBR traffic is characterized by a constant data transfer delay and a periodic availability of service quanta at the packet queues.

### 1.2 MAC Layer Protocols For Wireless LANs

Accessing a single wireless channel by many geographically distributed users is achieved through two basic types of multi-access techniques; i.e., Scheduled Access (SA) and

Random Access(RA) based on the amount of coordination required between the potentially conflicting users[12].

### 1.3 The proposed protocol

The proposed MAC layer protocol is designed for CBR and VBR data streams transmission on a single channel in wireless LANs. The protocol assumes that the node coloring algorithm has been run and each node has a color. The color of a each node is such that it has been used by any of the one hop neighbours. Each node can reuse the channel in the slot of its color.

Further, in every node of the network, there are two queues, one for CBR traffic and the other for the VBR traffic. The CBR packets are given higher priority than the VBR packets. The overall delay experienced by both the traffics are compensated by startup delays and buffer occupancy time at the receiver.

### 1.4 Organization of the rest of the paper

Section 2 describes the node coloring algorithm that is used by the protocol. Section 3 discusses the design of the protocol. Section 4 explains the delay analysis with two case studies illustrations. Section 5 gives the buffer estimation, and finally it concludes with Section 6.

## 2 Node Coloring Algorithm

The Wireless LAN considered, here, have nodes with sparse connectivity. The sparse connectivity of wireless LANs can arise from any of the following two factors.

- 1 The limited power of the transmitter when Microwave frequencies are used for transmission
- 2 The walls and other opaque obstacles and due to the limited power when transmission is carried out using infrared range of frequencies.

The area that a radio unit can cover with a given power is called the range of that unit. Due to the geographical separation of the units some units are shielded from the radiation

effects or range of the other radio unit. In this environment channel reuse in spatial domain is also possible apart from time and frequency domains. In this work we concentrate on the spatial reuse of the channel and consider how this can be used for simultaneous transmission of CBR and VBR traffic.

## 2.1 Definitions

1. Symmetric Network: A network where node  $i$  can transmit to node  $j$ , it can also listen transmissions from node  $j$ . The entire network can be represented by an undirected graph  $G=(V,E)$ , where  $V$  represents the set of all the radio units and  $E$  represents the set of all the edges between the radio units.

2. Neighbourhood: Consider the node  $i$  in the undirected graph  $G$ . The nodes that are directly connected to this node are called the one hop neighbours of node  $i$ . Let us denote this set by  $N1(i)$ . Now the neighbours of the set of nodes of  $N1(i)$  are called the two hop neighbours of  $i$  or the 2-neighbours. This set is denoted by  $N2(i)$ . The set that is sum of these two sets and denoted by  $N(i)$  is called the neighborhood of the node  $i$ .

## 2.2 Network Model

Consider a wireless network consisting of a finite number,  $p$  of radio units. In this work we presume radio as a medium for study. Each such radio unit can be represented as a node in a graph. If the radio unit( $i$ ) can transmit to radio unit( $j$ ) then we draw an arc from node ( $i$ ) to node( $j$ ) in the corresponding graph. It is possible that radio unit( $j$ ) can listen radio unit( $i$ ) but radio unit( $i$ ) cannot listen to radio unit( $j$ ).

### Assumptions

- 1 Every node in the network is identified by a unique number. This is a global identification used to distinguish one node from the other.
- 2 Every node knows identifies of all the nodes in its neighbourhood. This is the local connectivity that every node is assumed to have been equipped with.
- 3 Topology of the network is fixed. This is required to avoid possible changes in the neighbourhood information.
- 4 Nodes will not crash in the middle of the algorithm. Without this assumption there may arise situations where the other nodes may have to wait for this node indefinitely.
- 5 Messages sent by a node will be received correctly and control messages arrive in finite time.

*Each node of the network has the following lists.*

- The list of 1-hop neighbours called as list-1
- A set of flag for each neighbor, indicating whether a neighbor has already sent its list of neighbors. This list is called list-2.
- A list which stores for every neighbor and 2-neighbor, its assigned color(this is DUMMY at the initialization of the algorithm). This list is called the list-3.

## 2.3 Procedure to assign colors to nodes

Any non empty subset of nodes can initiate the algorithm. A node is going to start participating in the algorithm on receiving a WAKE message caused by an upper layer protocol or by the first reception of a message sent by another node executing the algorithm. On entering the algorithm each node broadcasts the list-1 to its neighbours. Nodes that receive this message use it for constructing list-2. On completion of the list-2 the node is waiting for the development of proper conditions for selecting a color. At a particular node this condition is obtained when that node becomes the node with the highest ID in list-2 and which has not yet been assigned a color. Following the color section, the node broadcasts its color to all its neighbours who, in turn, broadcast it to their neighbours. Thus the color assigned to a node is known to all its neighborhood.

The following rules are to be observed while updating the lists.

- 1 On reception of message by node  $i$  that a particular node, say node  $j$ , has selected a color, node  $i$  marks in its list-2 the color node  $j$  has selected.
- 2 When node  $i$  becomes the highest unmarked node in its list-2, it selects the smallest available color not chosen by any of the marked nodes in this list. Node  $i$  then marks its own entry in this list, registers the color, and broadcasts the selected color.

## 2.4 Illustration of the Node Coloring Algorithm

Consider a bus network with six nodes as shown in figure 1. Each node can transmit or receive from its immediate neighbor Node 3 receives a wake signal, then it broadcasts to its list of neighbors. The neighbors, ie., nodes 2 4 receive this message. Each of these nodes thus receives the neighbors of node 3, and adds them to their local list-2. Each of these nodes will now send its own neighbors list.

The list	Neighborhood	Color
1	{2, 3}	2
2	{1, 3, 4}	1
3	{1, 2, 4, 5}	0
4	{2, 3, 5, 6}	2
5	{3, 4, 6}	1
6	{4, 5}	0

**Table 1:** Colors for the nodes of newtwork illustrated in figure 1

Let us consider the position at node 3. On the reception of the neighbours information from node 2 and node 4 the list-2, which contains the list of neighborhood nodes, of node 3 consists of { 1, 2, 4, 5}. Since no neighbor of node 3 has been assigned a color and since it is not the node that has the highest node ID among its neighborhood node 3 has to wait for node 5 and node 4 to assign colours to themselves.

Now node 6 being the node with the highest ID among its neighborhood it assigns itself the color 0 and transmits this information to its neighbors. Node 5 notes this and transmits it to its neighbors. Now node 5 being the node with highest ID assigns itself the color 2 and sends it to its neighbors. Node 3 can now assign the color 0 itself as it is the lowest color not assigned in its neighborhood. Node 3 assigns this color and sends it to its neighbors. Similarly node 2 gets the color 1 whereas node 1 gets the color 2. Table 1 gives the colors assigned and the list-2 members of each node for the network shown in figure 1.

The problem addressed in this work is to distributively choose a maximum set of nodes for transmission at the same time, so that the CBR packets have as short delay as possible. This has to be achieved such that the packets do not undergo collision. The set of nodes so selected for simultaneous transmission should ensure that the receiver, as its neighbor.

This is ensured by using the node coloring algorithm of graph theory and by using the unique node identities.

### 3 The Protocol

#### 3.1 Motivation

We consider a situation in which there are two tyoes of trafics (CBR and VBR). If we allow the CBR traffic the exclusive use of the channel then much of the bandwidth of the channel goes unutilised. Therefore in our approach we do not guarantee the channel to the CBR traffic but the CBR packet also has to compete for the channel access along with the VBR packets. The jitter in the CBR traffic is eliminated with the use of appropriate size buffers at the destination. To get a reasonable number of buffers at the destination, the delays for the CBR packets should be small. To achieve thiswe need a protocol that uses the channel in an efficient man-

ner. The proposed protocol is efficient because it reuses the channel spatially and allows many users to utilize the channel simultaneously.

**Tables of CBR and VBR Packet Delays for Ring Network When the priority is 2:1**

VBR Packets Sent	CBR delay n sec	VBR Delay n sec
0.0000000	264.9848196	0.0000000
11742.0000000	461.3519285	0.0552823
23646.0000000	546.3816702	0.0863465
35426.0000000	623.6735297	0.1338812
47264.0000000	732.2625194	0.2442001
59098.0000000	861.8090589	0.6509484
70782.0000000	947.8922511	7.4271496
82302.0000000	885.3963634	58.7400215
93858.0000000	895.7826587	106.2075303
106020.0000000	926.3642506	168.0844664
117966.0000000	1059.6649428	254.4756826

**Table 2:** 100% of the nodes have appliations

VBR Packets Sent	CBR delay n sec	VBR Delay n sec
0.0000000	427.9270685	0.0000000
11736.0000000	223.9536947	0.0404312
23585.0000000	263.5816441	0.0495283
35302.0000000	599.0641013	0.1034821
47282.0000000	634.5468902	0.1662631
58776.0000000	687.0091369	0.3204305
70682.0000000	823.3019223	5.0248843
82418.0000000	664.2831919	7.1737955
94008.0000000	916.8346683	64.0625718
06432.0000000	822.2390514	103.4646770
17878.0000000	933.4001498	145.7682286

**Table 3:** 70% of the node have application

VBR Packets Sent	CBR delay n sec	VBR Delay n sec
0.0000000	0.0000000	0.0000000
11922.0000000	45.8789022	0.0328384
23779.0000000	70.2351497	0.0389314
35453.0000000	122.1510529	0.0477428
47307.0000000	181.5622605	0.06034531
59201.0000000	233.4942066	0.0735038
70815.0000000	326.4963872	0.0937319
82649.0000000	345.0373004	0.1675217
94672.0000000	420.7570259	0.2818811
105973.0000000	655.3575848	8.1841566
118479.0000000	771.6584731	16.0029341

**Table 4:** 30% of the node have application of the nodes have application

**Tables of CBR and VBR Packet Delays for Bus Network When the priority is 2:1**

### 3.2 Channel Access

#### Assumptions

We make the following assumptions other than what are already assumed under coloring algorithm.

- 1 Propagation delay is very low compared to packet transmission times.
- 2 There is a global clock for synchronization.
- 3 Processing delay incurred in learning the network activity is zero, i.e., to acquire the knowledge whether any neighbor is accessing the channel or not is learnt instantaneously.
- 4 Channel is slotted and data is transferred in the form of packets of appropriate size.

#### 3.2.1 Procedure for Accessing the channel

Once the coloring algorithm is run, all the nodes in the LAN will have a color. Let  $C_{max}$  be the maximum number of colors used by a node in the network. The channel is divided into frames and each frame is further divided into two parts, the control part and the data part.

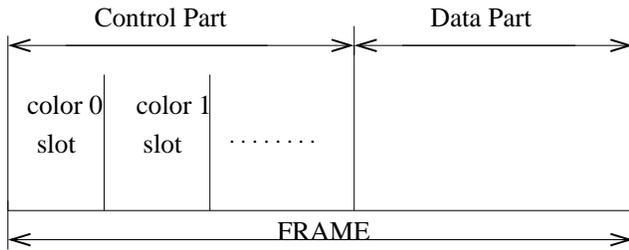


Figure 1: The Frame Structure

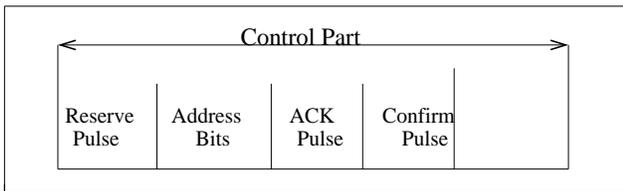


Figure 2: Details of the Control Slot

The data part is used for the transmission of the packet from the node that has reserved the channel for that particular frame in a particular region of the network. The control part is used for reserving the channel in that particular frame.

**Step 1:** The neighbors of this node might or might not send a NACK pulse. This is shown with the help of a dotted pulse in the above figure

**Step 2:** The node that tried to reserve the channel sends a confirmation pulse in the third mini slot if there was no NACK pulses. Otherwise it keeps silence this is shown with the help of dotted lines above

**Step 3:** The Node that tried to reserve the channel sends a confirmation pulse in the third mini slot if there was no NACK pulses. Otherwise, it keeps silence; this is shown with the help of dotted lined above

Figure 3: Steps involved in accessing the channel

The control part is further divided into  $C_{max}$  number of parts; i.e., it is divided into as many parts as the number of colors. So we have one slot for each color, each such part contains four mini slots. (see Figure 4). Figure 5 illustrates mini slots of a control slot.

Suppose a node that has particular color, say color 0, has a packet to send and wants to access the channel, it sends a pulse in the first mini slot of its colored slot, in this case it being the color zero slot, as shown in the step 1 of figure 4. The node also puts the address bits of the node to which it wants to send the data and then waits for ACK or NACK from the neighboring nodes. The neighbors of this node can send a NACK by sending a pulse in the third mini slot as shown in the step 2 of figure 4. If a node sends a NACK pulse then the node that desires to send data in the present frame will not do so.

The node that wants to reserve the channel, if it does not receive any NACK pulse in the second mini slot, it sends a confirmation pulse to its neighbors in the third mini slot as shown in the step 3 of figure 4. This sending of confirmation pulse is necessary as the neighbors should detect from listening in the present frame. These neighboring nodes to which there is no transmission and cannot listen in the present frame, can transmit to their neighbors if spatial condition permits. Once the node has sent a confirmation pulse it will send the packet in that frame. The node that has to listen to reservation confirmed (or source) node sends a NACK pulse to all its neighboring nodes, if they try to access the channel subsequently in the present frame and hence collision of packets is eliminated.

### 3.3 Fairness Problem

The proposed protocol at high arrival rates is unfair to the nodes that have colors of higher value. This is because at high arrival rates the nodes that have colors of lower value always have a packet in their queue and therefore always have the first choice in trying to access the channel. This leads to the building up of queues of the nodes that have higher valued colors.

This unfairness can be corrected if the colors of the nodes are rotated in each frame. In the proposed protocol this is achieved by increasing the value of the color of each node by one at the end of each frame and taking the modulus of the resulting value to the maximum number of colors.

### 3.4 CBR and VBR queue priorities

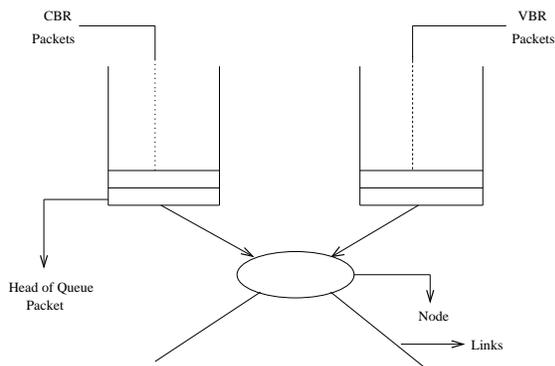


Figure 4: The CBR and VBR queues

The priorities of the CBR and the VBR queues are such that the CBR packets get a higher priority than the VBR packets. This type of priority is achieved by having tokens at every node. This token takes care when the CBR queue should be given priority over the VBR packets. Whenever a VBR packet is sent the token changes from VBR to CBR and after transferring the required number of CBR packets, which depends on the priority the token changes to VBR. However, if the token is with CBR, but there are no CBR packets available then the node might send the VBR packet if it is available and it is possible for it to access the channel. In such situations the CBR packet will not lose its chance as now the number of CBR packets sent queue is reset to zero and the whole priority scheme restarts from the beginning with the token taking the value CBR.

### 3.5 The Algorithm of the Protocol

All the nodes run the following algorithm simultaneously.

#### Nomenclature.

**Present-slot:** The name of the slot (whether control or data) at the particular node at the particular time.

**Present-color:** The color of the sub slot of the control slot at the particular node at the particular time.

**mycolour:** The color of that particular node

**mini-slot 1,2,3:** These slots are within the sub slot of the control slot. mini slot 1 refers to the slot where the node can put a reservation pulse and the address bits on to the channel. mini slot 2 refers to the slot where the node can send a NACK pulse to the node that has reserved the channel. mini slot 3 refers to the slot where the node that has reserved the channel should send a confirmation pulse.

---

```

begin
If(present-slot= control-slot)
begin
If(present-color = mycolour)
begin
/* depending upon the mini slot do the following*/
mini-slot 1: if there is packet to transmit send the reservation pulse and put the address bits.
mini-slot 2: wait and listen for any NACKs.
mini-slot 3: if no NACK during mini-slot 2 send a confirmation pulse otherwise keep silent.

end

else /* if present color is not my color*/
begin
/* depending upon the mini slot do the following */
mini-slot 1: listen to the channel for a possible reservation pulse from neighbor.
mini-slot 2: if there is reservation pulse from neighbor and the node is free
/* no reservation from other nodes */
Keep silent
otherwise /*if there is reservation from other nodes */
send a NACK pulse.
mini-slot 3: if there was reservation pulse during during the first mini slot and the node has not sent a NACK pulse listen for confirmation pulse.
end
end
else /* if the present slot is Data slot */
begin
if the node has sent a confirmation pulse during the third mini slot of the control part of its color send the packet at the head of the queue. Else keep quiet.
end
end

```

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## 4 Delay Analysis

The nine node Ring network and Bus network are simulated with two CBR applications per node and with different arrival rates of VBR traffic. The time duration's of the two

CBR applications in the nine nodes for the bus and the ring network is shown in the figure and distributions. In the figure the schedule is shown in terms of "Ticks" which was the smallest measurable time in the simulation and was equal to  $125\mu s$ .

#### Assumptions

- 1 Arrival of VBR pkts at every node follows Bernoulli distribution.
- 2 Each arrival to the system brings in only one packet of work load.
- 3 Destination for each packet is assumed to be uniformly distributed among the neighbors of that particular node for VBR packets whereas for the CBR packets each application has a specific node which it has to be sent.
- 4 The channel was considered to be wireless channel with capacity 10Mbs.
- 5 The channel was assumed to have negligible error rate. This means that any packet transmitted by source is sure to reach the destination without any errors.
- 6 The channel was assumed to be slotted with each slot duration being  $125\mu s$
- 7 The packets being transmitted were assumed to be of constant length. The length of each packet being equivalent to two slots. The constant packet length assumption is necessary for the proper working of the protocol.
- 8 Since the packets are routed to the destination through the neighbors of the source node only one hop delays were calculated.

In the simulation study of the proposed protocol various scenarios were considered like all the nodes(100%) having CBR applications, seventy percent of the nodes having CBR applications and 30% of the nodes having VBR applications. These studies were made at varying arrival rates of the VBR packets. It is assumed that there are two CBR applications running on each node. These two CBR applications are distributed randomly in the total simulation time was nine seconds.

The VBR packets arrive at their respective queues at Bernoulli arrival rates. The simulation and the delays were considered for various VBR arrival rates. The VBR packets are assumed to be of same length and the destination address of each VBR packet is assumed to be uniformly distributed among the neighbors of that particular node.

#### 4.1 Ring Network Simulation Results

The simulation was carried out for various priority schemes, i.e., 5:1, 3:1 and 2:1 of CBR and VBR packets respectively.

The simulation results of 2:1 priority scheme are tabulated in tables. The results of the other priority scheme as well as the 2:1 priority scheme are shown graphically in figures. Tables of CBR and VBR Packet Delay of Ring Network when the priority is 2:1.

VBR Packets Sent	CBR delay	VBR Delay
0.0000000	350.7687448	0.0000000
13302.0000000	379.2305773	0.0350511
26751.0000000	569.9390644	0.0633154
40038.0000000	648.1643376	0.1289213
53235.0000000	608.3372474	0.1939302
66610.0000000	753.3067448	0.529372
80030.0000000	930.2111263	11.4833672
93146.0000000	846.9894897	30.5681873
106173.0000000	836.5696959	77.0969420
119622.0000000	996.0550464	153.5898727
131936.0000000	859.4941469	153.2590906

**Table 5:** 70% of node have application

#### 4.1.1 Discussion

Consider the graph of CBR delay for the 2:1 priority scheme. It is seen that the maximum delay experienced by CBR packets is around 1059 ms. The maximum delay experienced by the CBR packets when 70% of the nodes have application is less than when 100% of the nodes have applications running on them. This can be explained that if more nodes with CBR applications compete for this transmission the delays or the CBR traffic increases.

In the case when there is only 30% of the nodes having CBR applications as the number of nodes vying for the channel is comparatively lower we see a marked decrease in the delays experienced by the CBR packets.

The delay of the CBR packets decreases when the priority scheme is changed to 3:1. At 3:1 priority the VBR packets are going to steal relatively less number of slots of the CBR packets and therefore decreases the queuing delay of the CBR packets. The CBR packet delay decreases as the priority scheme is changed to 5:1.

It is necessary to have short delays otherwise it becomes inconvenient for the to display these CBR packets. This is because the start-up delay increases proportionally to the increase in the CBR packet delay.

The VBR packet delay goes on increasing as the arrival rate of the VBR packets increases. This is again due to the fact that as the VBR traffic increases there is more number of packets vying for the channel and therefore some of the packets queue up and hence the delay increases. The delays experienced by the VBR packets is shown in tables.

The delay that has been obtained in the case study that has been conducted shows it is possible to display at the receiver with very less startup delay that is explained in detail in the

next chapter is very much essential to avoid jitter in the CBR stream.

## 4.2 Bus Network simulation Results

The results of the bus network simulation for the 2:1 priority scheme are given in tables 5, 6, 7. The graphs of 5:1, 3:1, and 2:1 priority schemes are tabulated in the table shown in figures. The maximum delay experienced by the CBR packets when the priority scheme is 2:1 and when 100% of the nodes have CBR application running on them is around 1401ms. This value of maximum delay reduces to only 745ms when only 30% of the nodes have CBR application running on them.

**Tables of CBR and VBR Packet Delays for Bus Network When the priority is 2:1**

VBR Packets Sent	CBR delay	VBR delay
0.0000000	461.8713018	0.0000000
13262.0000000	569.4657150	0.0340729
26476.0000000	525.5202046	0.0405462
39888.0000000	622.2979019	0.0636501
53424.0000000	752.2350296	0.1257557
66246.0000000	881.5169379	0.2955782
79828.0000000	946.8031016	1.5649208
92610.0000000	1073.6000740	33.0453096
105919.0000000	1134.7290212	58.4522808
119441.0000000	1285.9419305	87.6091899
132714.0000000	1401.1765582	187.2486964

**Table 6:** 100% of node have application

### 4.2.1 Discussion

It is found that the graphs follow the same pattern as that of the graphs of the simulation for a Ring Network but the CBR delays have increased slightly as compared to the Ring Network. This is due to the topological differences in the Ring and the Bus network. The Ring Network is different from the Bus network only in the fact that the end node's node 0 and node 8 are connected in the Ring Network whereas it is not in the case of the Bus Network. As a result of this the packets at node 0 and node 8 can also be routed through either of these nodes in the case of the Ring Network. This is not true in the case of Bus network and thus the packets at these nodes will have slightly greater delays. This explains the increase in delays for the Bus network.

## 5 Buffer estimation

The maximum CBR delay when hundred percent of the nodes have applications running on them with 2:1 priority is 1.401ms. Since the packet length we have assumed is 250ms the number of packets size buffers required is

1401/250, i.e., 600 packet size buffers. This translates to a buffer size of 600 bytes when the channel capacity is assumed to be 10Mbps. This buffer requirement is very small and can always be provided in any computer which has minimum configuration. The buffer requirements reduce as the percentage of nodes having CBR applications reduce. The buffers required for the VBR

VBR Packets Sent	CBR delay	VBR delay
0.0000000	0.0000000	0.0000000
13358.0000000	22.9677994	0.0105274
26568.0000000	52.0100948	0.0160390
39661.0000000	92.1662625	0.0223866
52650.0000000	145.1885180	0.0295347
66581.0000000	206.1144511	0.0399879
79250.0000000	263.8915569	0.0516688
93247.0000000	360.0018164	0.0754019
106239.0000000	449.6805589	0.1041214
119969.0000000	590.9135579	0.2251728
133286.0000000	745.8185629	3.5568908

**Table 7:** 30% of node have application packet is negligible.

The new protocol proposed reuses the channel spatially to the maximum extent. The number of maximum parallel transmissions is ceiling of  $n/3$  for ring network and is ceiling of  $n/2$  for bus networks, where  $n$  is the number of nodes in the network.

The coloring of the Nodes can be done distributively and hence there is no necessity of having a central Node.

Since the CBR packets experience the minimum delay the number of buffers required to be present at the destination node for playback is reduced because the number of buffers required for playback is minimum when the startup delay is minimum, which in turn is dependent on the maximum delay experienced by the CBR packets.

## 6 Conclusion

The proposed protocol is appropriate to be used in environments where the connectivity of the network is high.

The protocol does not guarantee any bandwidth for the continuous traffic and therefore the jitter in the continuous traffic has to be taken care of by the receiver.

## References

- (1) . K. Pahlavan, "Wireless Communications for office information networks," IEEE Communication Mag., Vol.23,No.6, pp. 19-27, June 1985
- (2) . C.A.Lynch and E.B.Brownrigg, Packet radio networks - Architectures, protocols, technologies and applications, Pergamon Press, Oxford, UK, 1987.
- (3) . T.S.Rapport, "Indoor Radio Communications for Factories at the Future," IEEE Communication Mag., Vol.27, No.5, pp.15-24, May 1989
- (4) . D.Buchholz, P.Odlyzko, M.Taylor and R.White, "Wireless In-Building Network Architecture and Protocols," IEEE Network Mag., Vol.5, No.6, pp. 31-38, November 1991.
- (5) . Mirjana Zafirovic-Vukotic and G.Niemegeers, "Multimedia Communication Systems: Upper Layers in the OSI-Reference Model," IEEE Journal on Selected Areas in Communications, Vol.10, No.9, December 1992, pp.1397-1401.
- (6) . T.S.Chu and M.J. Gans, "High speed infrared local wireless communication," IEEE Communication Mag., Vol.25, No.8, pp. 4-10, August 1987.
- (7) . J.M.Kahn, J.R.Barry et. Al "Non-Directed Infrared Links for High-Capacity Wireless LANs," IEEE Personal Communication Mag., Vol.1, No.2, pp.12-25, Second Quaterly, 1994.
- (8) . D.F. Bantz and F.J. Bauchot, "Wireless LAN Design Alternatives," IEEE Network mag., Vol.8, No.2, pp.43-53, March/April 1994.
- (9) . Andrew S. Tannenbaum "Computer Networks," Second Edition, Prentice-Hall of India, 1994.
- (10) . M.B. Pursley, "The role of spread spectrum in packet radio networks," Proc, IEEE, Vol.75, No.1, pp.116-134, January 1987.
- (11) . J.S. Storey and F.A. Tobagi, "Throughput performance of an Unslotted direct sequence SSMA packet radio network," IEEE Trans. Commun., Vol.37, No.8, pp.814-823, August 1989.
- (12) . L.Kleinrock and F.A. Tabagi, "Packet switching in radio channels: PartI - Carrier sense multiple access modes and their throughput-delay characterstics," IEEE Transactions on Communication, Vol. COM-23, No.12, pp.1400-1416, December 1975.
- (13) . I.Chlamtac and S.S.Pinter, "Distributed Nodes Organisation Algorithm for Channel Access in a Multihop Dynamic Radio Network," IEEE Transactions on Computers, Vol.36, No.6, June 1987, pp.728-737.