# EFFECT OF PROPAGATION AND PROCESSING DELAYS ON THE THROUGHPUT PERFORMANCE OF A CLASS OF MULTIACCESS PROTOCOL FOR HIGH SPEED RADIO LANS

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### Abstract

In this paper, we present the design and throughput performance of a multiaccess protocol applicable to fully connected and homogeneous High Speed Radio LANs. The protocol utilises a slotted message channel and an independent busy tone channel. The messages constitute multiple data packets and each packet occupies one slot duration. To study the throughput performance of the protocol a simulation model has been developed for Bernoulli arrivals and Geometric distribution of message lengths. The results show that while the propagation & processing delays degrade the throughput increasingly with the 'Delay Constant'—a factor equal to the smallest integer greater than or equal to the ratio between the two way radio propagation & processing delays to the packet duration—the protocol still is found to offer good throughputs of the order of 0.4 – 0.7 for Radio LANs up to 100 Mbps rate and 10 Kms range.

## 1 Introduction

Radio LANs (also referred as Cableless LANs or Wireless LANs) are becoming increasingly popular for local area and in-building data communications due to the key advantages like easy terminal relocatability and flexible reconfigurability of the network at minimum cost and logistics [1]. They are also suggested for applications like networking for library and factory automation using radio terminals–mostly static–to overcome the problem of laying interconnecting LAN cables across buildings. Conventional Packet Radio Networks (PRN) operate at typical data rates up to 500 Kbps—e.g., Stanford Packet Radio Network operating at 56 Kbps [2], and DARPA Packet Radio Network operating at 100 Kbps and 400 Kbps. An experimental 1 Megabit Packet Radio Network is presented in [3]. Radio systems at various frequency bands employed for local networking applications are reported in [4],[5]. The medium access protocols play a vital role in determining the network efficiency in terms of throughput and delay performance. Scheduled Access (SA) protocols like TDMA, Random Access (RA) protocols like ALOHA, Slotted ALOHA, CSMA & Busy Tone based protocols and Spread Spectrum Multiple Access (SSMA) have been studied for packet radio networks [6],[7].

While the packet radio activities have so far been in the low to medium data rate area, there is increasing need for high speed networking and protocol study in multi-megabit ranges to carry integrated services. Recent developments in the radio transmission technology have shown vast increase in the radio channel capacities in terms of both power and bandwidth. Radio transmission capacities up to a rate of 140 Mbps within 20 MHz bandwidth have been shown to be a commercial viability [8], while development activities are on to push the transmission rate further beyond [9]. The multiaccess protocols used for conventional PRNs at low and medium speeds can not be directly applied to high speed radio networks because the packet transmission time becomes less than the propagation delay thus demanding either new protocol designs or modification of the existing protocols. In this paper, we present the modified version of a busy tone based Optimum Channel Utilisation Multiaccess (OCUM) protocol suitable for High Speed radio LANs. In section 2, we briefly describe the OCUM protocol. Section 3 describes the design of the Modified OCUM protocol and provides the simulation results illustrating effect of propagation & processing delays on the throughput. Section 4 presents the conclusions highlighting further relevant investigations.

## 2 OCUM Protocol

In our earlier attempts, an Optimum Channel Utilisation Multiaccess (OCUM) protocol [7] based on an independent busy tone channel concept suitable for fully connected and homogeneous PRNs has been designed and analysed. The OCUM protocol utilises a slotted message channel (M-Channel) and an independent busy tone channel (B-Channel). The messages constitute multiple data packets and each packet occupies one slot duration.

In the assumed system, when a node gets a message arrival, it blocks further arrivals until the current message is successfully transmitted to the destination. If a node finds the busy tone being present on B-Channel, it reschedules the transmission attempt to a later time. In the absence of busy tone, it sends a *preamble packet* (which contains the destination node address in its address field) on the M-Channel and expects the busy tone ACK from the des-

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tination node in the next immediate slot. The destination node receives the preamble packet correctly and broadcasts the busy tone ACK, if not more than one node has transmitted the preamble during the same slot. If more than one node had sent preambles in the same slot, due to collision none of the destination nodes would receive the preamble packet correctly and thus no busy tone ACK is broadcast. In the event of the busy tone ACK being received immediately, the sender node transmits the data packets continuously on M-Channel until the entire message transmission is completed and then waits for a new message arrival. On the contrary, if the busy tone ACK is not received, the sender node again reschedules the transmission attempt to a later time.

The OCUM protocol throughput performance has been studied using Markov Chain analysis for a 'N' node network with zero propagation & processing delay assumption. The analytical model assumes Bernoulli arrival process with arrival rate of '$\lambda$' per slot at each node and Geometric distribution of message length in number of packets with parameter '$g$'. The steady state equation for throughput ($\eta$) has been derived as

$$\eta = \frac{(1+g)N\lambda(1-\lambda)^{N-1}}{g + N\lambda(1-\lambda)^{N-1}} \tag{1}$$

Maximum throughputs of the order of 0.7 – 0.9 are achieved and are found to occur at the arrival rate of $\lambda = \frac{1}{N}$. It is also noted that higher values of throughput are realised for lower values of '$g$' ie., for larger message sizes.

## 3 Modified OCUM Protocol

In the OCUM protocol described above, the zero propagation & processing delay assumption has been made. This assumption is valid for networks satisfying the condition ($t_d/t_p \ll 1$) where $t_d$ is the two way propagation & processing delay between sender and receiver node and $t_p$ is the packet duration. However, the zero delay assumption becomes invalid for high speed PRNs operating in multimegabit ranges since the ratio ($t_d/t_p$) becomes greater than one and the OCUM protocol fails as the delay between the preamble transmission and busy tone ACK reception leaves a *vulnerable time zone* where sensing of the B-Channel is not meaningful. Thus, it becomes necessary to modify the OCUM protocol for high speed radio networks. In this section, we present the Modified OCUM (MOCUM) protocol and its throughput performance.

Consider $\mathcal{S}(1 \mathinner{..} \mathcal{N})$ be the set of nodes in the network where the connectivity among the nodes is defined by the matrix $\mathcal{L}(\mathcal{N} \times \mathcal{N})$ such that the element

$$\ell(i,j) = \begin{cases} 1 & \text{if nodes } i \text{ and } j \text{ are connected} \\ 0 & \text{otherwise} \end{cases}$$

Assume that full connectivity exists between all the nodes such that for any pair of nodes $(i,j)$, $\ell(i,j) = 1 \; \forall \, (i,j),\, i \neq j$. The two way propagation & processing delay '$t_d$' elapsed between the preamble transmission and the busy tone receive at a sender node has four components viz., propagation delay between the sender node and receiver node during the preamble transmission ($t_1$), preamble processing delay at the destination node ($t_{p1}$), propagation delay between the receiver node and sender node during the busy tone transmission ($t_2$) and the busy tone detection delay at the sender node ($t_{p2}$) such that $t_d = t_1 + t_{p1} + t_2 + t_{p2}$ as illustrated in Fig(1). Without loss of generality, let us assume that the total propagation & processing delay is equal to '$k$' number of M-Channel slot durations. ie.,

$$t_d = kt_p \qquad k = 0,1,2,3,... \tag{2}$$

where '$k$' is the delay constant. Once the receiver node stops busy tone transmission, it takes '$k$' slot delay for the sender node and other nodes to be aware of the busy tone absence on the B-Channel. Refer Fig(1).

Let $d_{ij}$ represent the distance between the node $(i,j)$ pair. Then, propagation delay between nodes $i$ and $j$, $t_{ij} = \frac{d_{ij}}{c}$ where '$c$' is the velocity of radio wave propagation. Assuming processing delays to be constant, the total two way propagation & processing delay between any node pair $(i,j), T_{ij} = 2t_{ij} + t_{p1} + t_{p2}$. The inter node distances are such that the condition

$$\lceil \frac{T_{ij}}{t_p} \rceil = k \quad \forall \, (i,j),\, i \neq j \tag{3}$$

is satisfied.

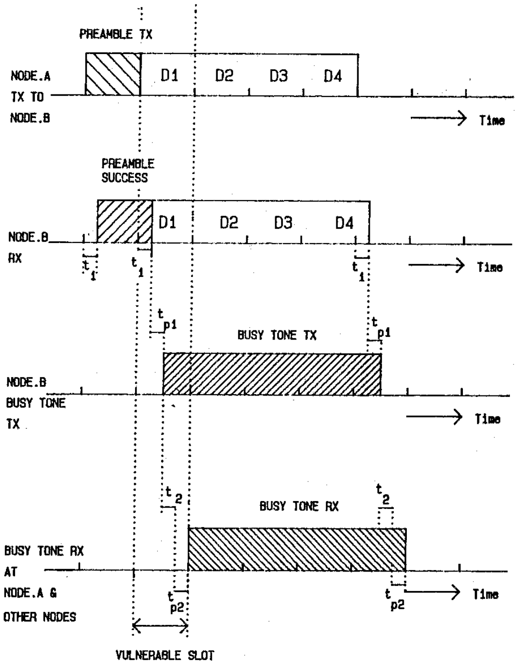

FIG. 1. Illustration of preamble success in slot 'n' & no new tx. attempt in vulnerable slot(s) 'n+k'. (k=1)

## 3.1 Protocol operation

On message arrival, based on the availability of busy tone on the B-Channel, a node reschedules or schedules the transmission attempt. A transmission attempt, made by sending the *preamble packet* on the M-Channel, is followed by transmission of data packets in the subsequent slots. To find out whether the preamble has been successfully transmitted, the sender node expects the busy tone ACK from the destination node in the $(k+1)^{th}$ slot after the preamble slot. During this *'k'* slot response time interval *(referred to as the vulnerable slots)*, one of the following events can occur.

### 3.1.1 Preamble Success

The preamble transmission is successful and the busy tone is received by all nodes after *'k'* slot duration ie., in $(k+1)^{th}$ slot after the preamble slot. No other node attempts transmission in the *'k'* vulnerable slots. During the vulnerable slots, the M-Channel is not left idle but data packets are continuously transmitted assuming that there is no preamble collision. This situation for $k = 1$ is shown in Fig(1).

Following the successful transmission of preamble by a sender node, it is possible that other nodes send their preambles and subsequently data in any of the *'k'* vulnerable slots. When this occurs, *i)* the node(s) attempting preamble transmission in any of *'k'* vulnerable slots will corrupt the data packets of the successful sender resulting in a loss of minimum one and maximum *'k'* number of data packets and *ii)* the intruding node(s) will receive the busy tone earlier than expected (ie., in less than *'k'* slots) which would mean that already there exists a successful sender transmitting data packets. The intruding node(s) will then terminate their data transmission to avoid further loss of packets to the successful sender. Fig(2) illustrates this case for $k = 1$. The sender node continues data transmission until the entire message is sent and there upon the destination node stops the busy tone broadcast. The M-Channel then becomes available after *'k'* slot duration.

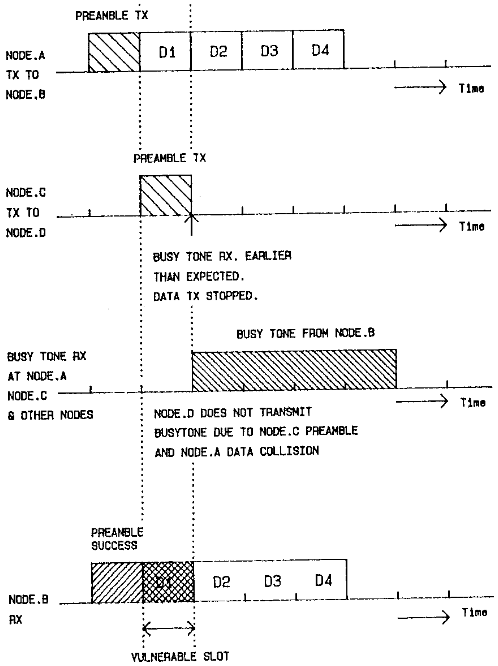

FIG. 2. Illustration of preamble success in slot 'n' & new tx. attempt in vulnerable slot(s) 'n+k'. (k=1)

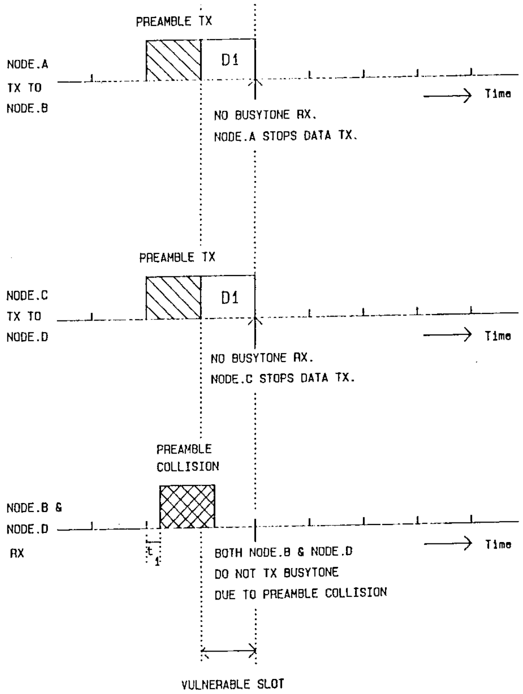

FIG. 3. Illustration of preamble collision in slot 'n' & no new tx. attempt in vulnerable slot(s) 'n+k'. (k=1)

### 3.1.2 Preamble Collision

Two or more nodes attempt transmission in the same slot resulting in preamble collision and no transmission attempt is made in the *'k'* vulnerable slots. In this case no busy tone ACK is received in the $(k+1)^{th}$ slot after the preamble slot since all preambles transmitted would have got corrupted. All the attempting nodes while waiting for the busy tone would have sent (and lost) data packets in the *'k'* vulnerable slots. No busy tone ACK condition after *'k'* slots will force the attempting nodes to stop their data transmissions and schedule for retransmission later as illustrated in Fig(3).

It may be further noted that other nodes trying to send their preambles in the *'k'* vulnerable slots following a preamble collision slot will also suffer collision and reschedule their transmission attempts subsequently. This situation is illustrated in Fig(4).

The algorithmic representation of the MOCUM protocol transmit and receive procedures are given below.

{ Nomenclature used: *msg* := message; *arrl* := arrival; *retx* := retransmission; *chl* := channel; *pckt* := packet; *slt* := slot; *Kvul_slts* := 'k' vulnerable slots; *destn* := destination; *addr* := address; }

```
MOCUMP transmit_procedure();
BEGIN()
    WHEN (msg_arrl) IS TRUE
        {
            BLOCK (new_arrl);
            SENSE (B_chl);
            IF (B_chl) IS BUSY THEN RESCHEDULE_TX;
            ELSE
              {
                SEND (preamble_pckt) ON (M_chl);
                SEND (data_pckts) ON (M_chl);
                SENSE (B_chl);
                IF (B_chl) EQUALS
                    BUSY IN LESS THAN (Kvul_slts)
                                OR
                    FREE IN $((k+1)^{th}$_slt) THEN
                    {
                        STOP (data_pckts) ON (M_chl);
                        RESCHEDULE_TX;
                    }
                IF (B_chl) EQUALS BUSY IN $((k+1)^{th}$_slt) THEN
                    {
                        SEND (data_pckts) ON (M_chl) UNTIL (msg_end);
                        GOTO BEGIN();
                    }
              }
        }
END().
```

```
MOCUMP receive_procedure();
BEGIN()
    RECEIVE (preamble_pckt) ON (M_chl);
    COMPARE (self_addr) WITH (destn_addr);
    IF (self_addr) EQUALS (destn_addr) THEN
        {
            BROADCAST (busy_tone);
            RECEIVE (data_pckts) ON (M_chl) UNTIL (msg_end);
            STOP (busy_tone);
        }
END().
```

## 3.2 Simulation

A simulation study has been carried out to estimate the throughput performance through a discrete event simulation package implementing the MOCUM protocol. The simulation model is characterised by *Bernoulli* arrival process with rate '$\lambda$' per slot at each node and *Geometric* distribution of message length with parameter *'g'*. Throughput and channel capacity values for various settings of the network parameters like number of nodes in the network (N), arrival rate ($\lambda$), average message length ($1/g$) and propagation & processing delay constant ($k$) are obtained.

The various values of *'g'* used in the simulation study are 1, 0.5, 0.2, 0.1, 0.05, 0.02, 0.01 which correspond to average message lengths of 1, 2, 5, 10, 20, 50 and 100 respectively. The effect of propagation & processing delay for *'k'* values of 0, 1, 2, 3 and 4 have been studied. Fig(5) illustrates the throughput performance for $N = 5, g = 0.1$ and $k = 0,1,2,3,4$. It is observed that a maximum throughput (channel capacity) of 0.89 is achieved for $k = 0$ and it degrades to 0.73 for $k = 1$, 0.6 for $k = 2$, 0.5 for $k = 3$ and 0.45 for $k = 4$. It is noted that the simulation results for $k = 0$ case illustrated in Fig(5) match well with the throughput values calculated from Equation (1) that is derived through Markov chain analysis. Fig(6) shows the variation of channel capacity for different average message lengths for $N = 20$ and $k = 0,1,2,3,4$. The results indicate that the channel capacity offered by the protocol increases with increasing message lengths.

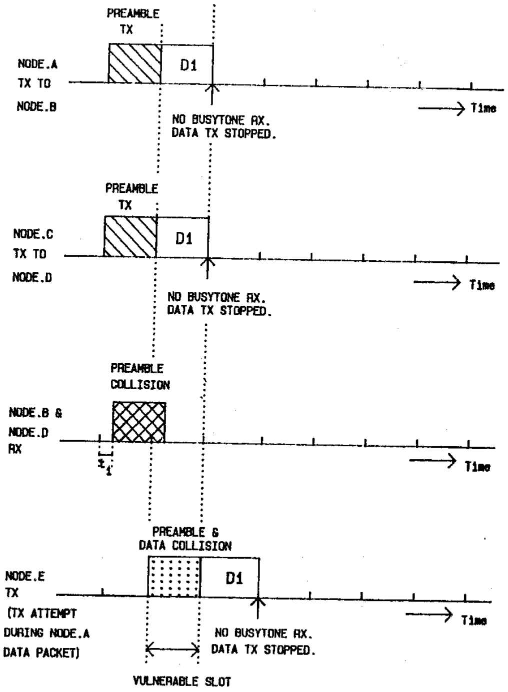

FIG. 4. Illustration of preamble collision in slot 'n' & new tx. attempt in vulnerable slot(s) 'n+k'. (k=1)

We studied the performance of the MOCUM proto-

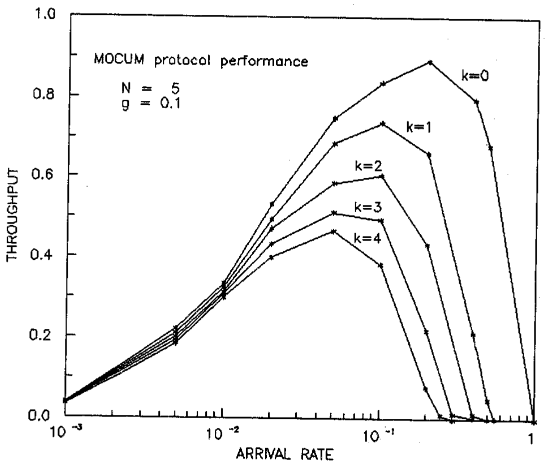

FIG. 5. Throughput versus arrival rate for N=5, g=0.1 and k=0,1,2,3,4

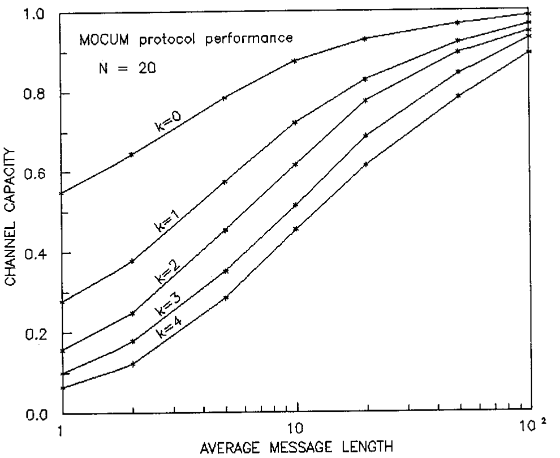

FIG. 6. Channel capacity versus average message length for N=20 at different values of k

col for high speed LAN environment. A high speed radio LAN operating at 100 Mbps rate is considered. A typical packet size of 1000 bits and processing delay of 2 $\mu sec$ is assumed. The channel capacity is estimated as a function of internode distance for different network parameters. Fig(7) shows the channel capacity variation for a 20 node, 100 Mbps Radio LAN for internode distances ranging up to 10 kms. It is shown that the channel capacity varies between 0.7 to 0.4 for different internode distances that characterise a typical LAN environment.

## 4 CONCLUSION

We presented an Optimum Channel Utilisation Multiaccess protocol based on an independent busy tone channel concept applicable to High Speed Radio LANs. The throughput performance of the protocol estimated through a simulation model and the effect of propagation & processing delays on the throughput were discussed. It was pointed out that the protocol offers throughputs of the order of 0.4 - 0.9 for Radio LANs operating up to 100 Mbps data rate over 10 Kms range. Further, performance studies like the message transfer delay characteristics and the effect of *capture*—a phenomenon by which when radio nodes of unequal powers transmit simultaneously, the transmission with higher power is received correctly—on this protocol are envisaged.

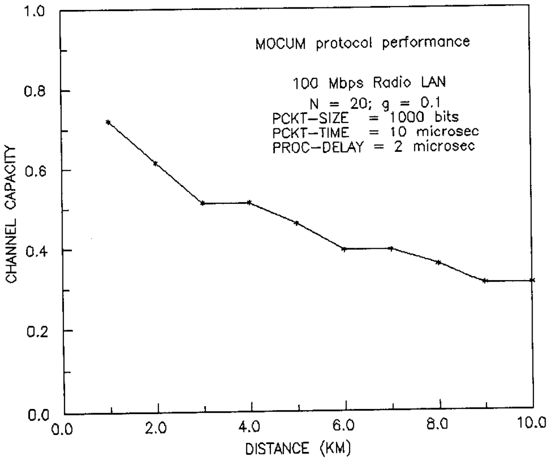

FIG. 7. Channel capacity versus distance for 100 Mbps Radio LAN

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