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MULTIPLE ADDRESS FACILITY FOR PACKET RADIO; AN
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ESTABLISHMENT MALVERN (ENGLAND) C J GORE NOV 87

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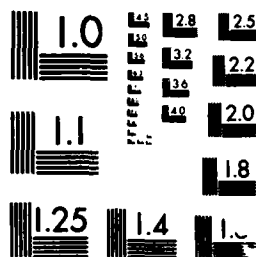
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ROYAL SIGNALS AND RADAR ESTABLISHMENT

Memorandum 4096

TITLE: MULTIPLE ADDRESS FACILITY FOR PACKET RADIO: AN INVESTIGATION
OF PERFORMANCE/COMPLEXITY TRADE OFF

AUTHOR: C J Gove

DATE: November 1987

SUMMARY

The implementation of a multicast protocol on the packet radio network simulator has been initiated in an attempt to investigate the performance/complexity/efficiency trade off of multiple address protocols in narrowband packet radio networks.

A multicast data packet has an address list of up to 8 destinations together with a list of selected relay units. The list of destinations with an amended list of relay units will be included in the data packet transmitted by each identified relay unit.

All the results produced are a product of the RSRE Packet Radio Network computer simulation (Reference 1) that had been adapted from a single destination packet, with node by node acknowledgement only, to a multiple destination packet with destination to source acknowledgement. The packets are transmitted with the aim of a fast, reliable, efficient delivery together with a slow but efficient acknowledgement of that delivery.

The results obtained, displayed an overall improvement in data throughput with a general reduction in the number of transmissions required to obtain the increased packet delivery. With the limited information throughput existing with the narrow band packet radio protocol any improvement in throughput is considered significant.

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List of Contents

1. Introduction
 2. Basic Concept
 3. Review of Tests and Results
 4. Conclusion
 5. Acknowledgement
 6. Reference
- Appendix A

1. INTRODUCTION

The existing Packet Radio Network Simulator provides for the transmission of an unacknowledged, on an end to end basis, data packet being relayed to a single destination unit.

The modifications have been implemented to provide a positive acknowledgement, at the source unit, from all the intended recipients of the data packet. The solution provides for rapid packet delivery to all the destinations but uses a slow acknowledgement where each acknowledgement hitch-hikes with routing and data packet transmissions and no special "acknowledgement only" transmissions contemplated. The acknowledgements are merged as they are received by units closer to the original source unit and are thus often transmitted more than once.

The previous protocol implemented both as a simulation and on 5 laboratory prototypes have provided results that show a figure of less than 2 kilobits of user data is reliably transmitted every second when using a narrowband packet radio network (Reference 2). Therefore it is important to identify methods that lead to improvements in the efficient use of the channel. The results provided by the multicast protocol are therefore made more significant.

2. BASIC CONCEPT

To improve the efficiency of the dissemination of information from a source unit to a number of destinations. In an all hearing group of Packet Radio Units, with the existing (original) protocol, the number of transmissions required will be the number of destinations. If the information needs to be relayed to reach the destination then the number of transmissions required is further increased.

The multicast protocol takes advantage of the omnidirectional transmissions from the packet radio and the knowledge that the transmitted packet is going to be received by more packet radio units than the intended recipient. Figures 1 and 2 illustrate the increases in efficiency obtainable with the multicast protocol.

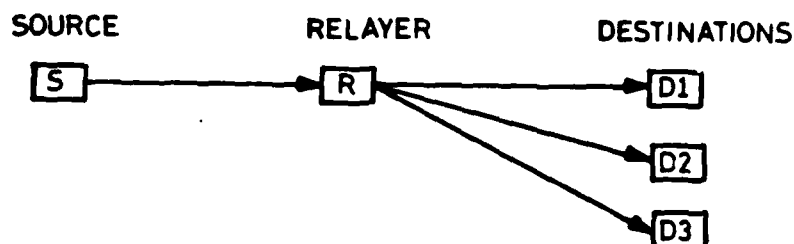


Figure 1

Original Protocol
 Transmissions required
 = (Source --> Relay) + (Relay --> Destination 1)
 + (S --> R) + (S --> D2)
 + (S --> R) + (R --> D3) = 6 transmissions

Multicast Protocol
 Transmissions required
 = (S --> R) + (R --> D1,D2,D3) = 2 transmissions

The number of transmissions reduced to a third.

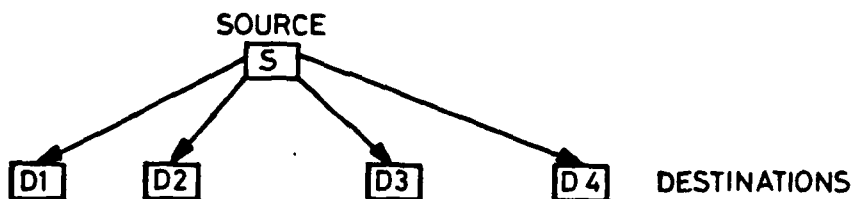


Figure 2

Original Protocol
 Transmissions required
 = (S --> D1) + (S --> D2)
 + (S --> D3) + (S --> D4) = 4 transmissions

Multicast Protocol
 Transmissions required
 = (S --> D1,D2,D3,D4) = 1 transmission

The number of transmissions reduced to a quarter.

The multicast protocol will reduce, for multiple destination packets, the number of transmissions required to achieve delivery by at least 20% and generally the saving will better this figure.

The other enhancement over the original protocol is the ability to inform the source unit, of the delivery of the packet to each of the destinations. The delivery acknowledgement is not transmitted as a separate packet but allowed to hitch-hike with other transmissions from the destination unit. The relay unit will receive the transmissions, collate the acknowledgements and forward the information towards the source unit with any subsequent transmission. The penalty of this operation is that a significant period can elapse before the full acknowledgement is delivered to the source unit.

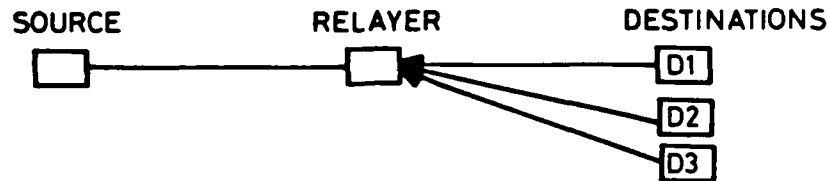


Figure 3

The acknowledgements of packet arrival at the destinations (D1,D2,D3), as displayed in figure 3, are collated by the relay unit (R) on hearing the acknowledgements contained in subsequent transmissions from D1,D2,D3 for onward relaying to the source unit(S).

A limit of one multicast packet per Packet Radio Unit (PRU) outstanding at any one time. The remainder of packets generated will be for a single destination although the delivery is still acknowledged to the source unit.

A multicast packet is capable of being addressed to a maximum of eight and a minimum of two destinations. A relay unit is selected for each packet destination.

On generation, a packet is created and a record inserted in MY QUEUE, the new packet queue for each PRU.

When a new packet is selected for transmission, two new records are created and MY QUEUE record deleted. The records created are

- a) an entry in RETX QUEUE list
- b) an entry in ACTIVE QUEUE list.

RETX QUEUE record is used to maintain the packet while it is still available for transmission. The relay and acknowledgement maps are bit maps where each bit in the byte, maps the physical position in the destination address list, that is one bit for each of the eight possible destinations. The relay map (which is local to the transmitting PRU) when used in conjunction with the relay address list, will indicate whether the transmitting unit is still required to make further transmissions of the packet. A bit set to '0' indicates that the selected relay unit has not responded with an acknowledgement of the previously transmitted packet therefore a further attempt to relay the packet is required. A bit will be set to '1' on receipt of the acknowledgement from the relay unit and all the bits relating to the relay/destination units set to 1 after 4 transmissions have been made. When the selected relay units, for a particular packet transmission, are all set to '1' then no further attempts are made to transmit the packet and the record is removed from the RETXQUEUE.

ACTIVE QUEUE record maintains the information regarding the packet throughout its active life. Each relay unit and destination unit creates a copy of the active queue record on the initial reception of the packet. The acknowledgement map records the packet delivery at the destination, the bit representing the packet destination unit is set to '0' to show non delivery and set to '1' on delivery of the packet. The acknowledgement map will be included with subsequent transmissions from the destination unit. Units receiving the transmission and having previous knowledge of the packet will collate the information together with acknowledgement maps received from other destinations of that packet and through further transmissions, the acknowledgements percolate towards the originating unit.

PASSIVE QUEUE record is the record of a packet previously received by the unit and is no longer required to be active, ie the acknowledgements are no longer transmitted. The record can be restored to the active queue if a packet acknowledgement is received with a different acknowledgement map. The record can be purged after a period of inactivity.

The record will be transferred from the ACTIVE QUEUE to the PASSIVE QUEUE

- a) on completion of 4 attempts to transmit the packet.
- b) on receipt of an acknowledgement map with the same identification and containing the same information and that information remaining unchanged for a period of time.

All the records RETX QUEUE, ACTIVE QUEUE and PASSIVE QUEUE will be purged on receipt of a second clear command from the original source unit. This command indicates that the packet has been fully acknowledged to the originating unit.

Worked Example

The assumption is made that only one transmission per hop is required to relay the packet to the destination/relay unit.

Network - 3 groups and 2 overlap areas

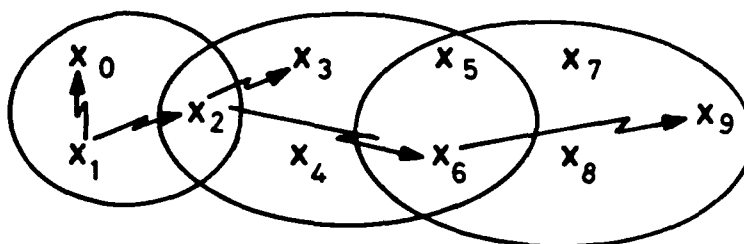


Figure 4

where

X represents a PRU in a hearing group
 (a PRU within an overlap area can hear
 transmissions from two hearing groups)
 X4 represents a PRU with identification number 4.

Pkt. Id. No. : 17
 Source Unit Id. : 1
 Number of destinations : 4
 Destination Unit Ids. : 0, 3, 6, 9, -1, -1, -1, -1
 (where -1 represents a non destination)

Outward Journey

Tx. Unit : 1
 Dest. Units 0,3,6,9,-1,-1,-1,-1
 Relay Units 0,2,2,2,-1,-1,-1,-1
 Relay Map : 11 110 000
 Acknowledgement Map : 00 000 000

Tx. Unit : 2
 Dest. Unit 0,3,6,9,-1,-1,-1,-1
 Relay Unit -1,3,6,6,-1,-1,-1,-1
 Relay Map : 11 110 001
 Acknowledgement Map : 00 000 000

Tx. Unit : 6
 Dest. Unit 0,3,6,9,-1,-1,-1,-1
 Relay Unit -1,-1,-1,9,-1,-1,-1,-1
 Relay Map : 11 110 111
 Acknowledgement Map : 00 000 100

On receipt of the packet at the destination, the unit will insert a '1' in the acknowledgement map relative to the position of the unit in the destination list. For example, destination unit 6 which is located at position 3 in the destination list will insert a '1' in bit position 3 in the acknowledgement map. (the least significant bit of the acknowledgement map is bit 1)

Inward Journey

The Acknowledgement Map for Pkt. Id. 17 will be included in subsequent transmissions from the following PRU.

The initial state of the acknowledgement map held by the units shown below before the reception of further transmissions containing data relating to packet identification number 17.

PRU	Acknowledgement Map
0	00 000 001
1	00 000 000
2	00 000 000
3	00 000 010
6	00 000 100
9	00 001 000

Subsequent transmissions. Only the transmissions that convey different acknowledgement information are displayed to demonstrate the hitch-hike principle for the transmission of the acknowledgement map on the inward journey. This reduced display will clarify the route taken. The transmissions are shown unrealistically to take place in the numerical order of the unit's identification and will not be expected to follow this sequence within the simulator. Once again it has been assumed that only one transmission per hop is required to deliver the acknowledgement.

Transmitting unit		Receiving units		
PRU	ack. map	PRU	Acknowledgement Maps	
			pre reception	post reception
0	00 000 001	1	00 000 000	00 000 001
		2	00 000 000	00 000 001
3	00 000 010	2	00 000 001	00 000 011
6	00 000 100	2	00 000 011	00 000 111
9	00 001 000	6	00 000 100	00 001 100
2	00 000 111	1	00 000 001	00 000 111
		2	00 000 111	00 001 111
6	00 001 100	2	00 000 111	00 001 111
2	00 001 111	1	00 000 111	00 001 111

3. REVIEW OF TESTS AND RESULTS

The aim of the Multicast simulator investigation is to ensure that the protocol is viable and that the expected improvement in throughput of information, when compared with the original single destination simulator, is achievable and that the penalty paid for this improvement is within acceptable bounds. The one overhead identified is the large number of acknowledgements required to be included in the packet to achieve the acknowledgement rates.

The tests have been carried out using a selection of networks, a single hop, all hearing network of 25 users and two multihop networks of 25 and 14 users of different complexity as regards the number of units in the relay position. (Appendix A) Throughout the tests the simulated runtime has been for a uniform period of 900 seconds with a choice from two levels of activity, 10% and 70%. (packet generation rate)

For 10% activity a packet is attempted to be generated every 10 packet times + a random element. (1 packet time = 100 milliseconds)

i.e. approximately 1 packet generated per second.

For 70% activity a packet is attempted to be generated every 1.4 packet times + a random element.

i.e. approximately 6 packets generated per second.

The simulator generates packets with multiple destinations in the range, 2 to 8 destinations with an average of 3 to 5 destinations per packet. The choice is random and the only constraints placed on the selection of the destinations are :

- a) a unit cannot transmit a packet to itself
- b) cannot duplicate a selected destination address.

Of the packets accepted by the network the delivery of multicast packets both at high and low activity rates does show a high level of successful delivery and shows a significant improvement over the delivery levels displayed in the single destination (original) simulation. With the multicast simulation, the majority of packets (both single and multiple destination packets) are shown to be delivered to the destination within the first few seconds of the initial transmission. The round trip time for the acknowledgements of multicast packets is such that greater than 90% of packets delivered are acknowledged within 60 seconds. The delivery of packets to the destination unit is demonstrated to be greater than 90% of packets are delivered within 20 seconds from the initial transmission.

The graphs (Figures 5 - 8) illustrate the comparison between the packet delivery delay periods and the spread of the arrival of the acknowledgements at the source unit. The timing for the delivery delay commences with the initial transmission and the acknowledgement graph shows the delay period for a multiple destination packet being completely acknowledged. The graphs also emphasise the different results achieved with the different network topologies.

Number of Packets Accepted for Transmission

Activity %	Network A		Network B		Network C	
	Multi No.	Orig No.	Multi No.	Orig No.	Multi No.	Orig No.
10	857	824	750	798	609	745
70	4449	3968	1050	1876	691	1696

Table 1

Network A
25 Units : all hearing

Activity	Packet Deliveries		Packet Transmissions		Percentage Increase / Decrease (Multi/Orig)	
	Multi	Orig	Multi	Orig	Del.	Tx.
%	No.	No.	No.	No.		
10	2950	823	2263	1955	+258	+ 16
70	9232	3900	5610	6160	+136	- 9

Network B
25 Units : 4 hearing groups with 3 overlap areas

10	1937	798	4360	3059	+143	+ 43
70	2320	1706	5787	8866	+ 36	- 35

Network C
14 Units : 4 hearing groups with 3 overlap areas

10	1545	741	3560	2527	+109	+ 41
70	1497	1617	3834	7292	- 7	- 47

Table 2

The results (in Table 2, with reference to Table 1) show the reduction in the number of transmissions required to achieve the improved delivery levels for the multicast protocol in comparison with the original protocol. The improvement in the number of data packets delivered and the reduction in the number of transmissions required are shown to be significant when compared with the results from the original version of the simulator. The benefits are increased for the higher levels of activity.

Packet Delivery Delay Periods

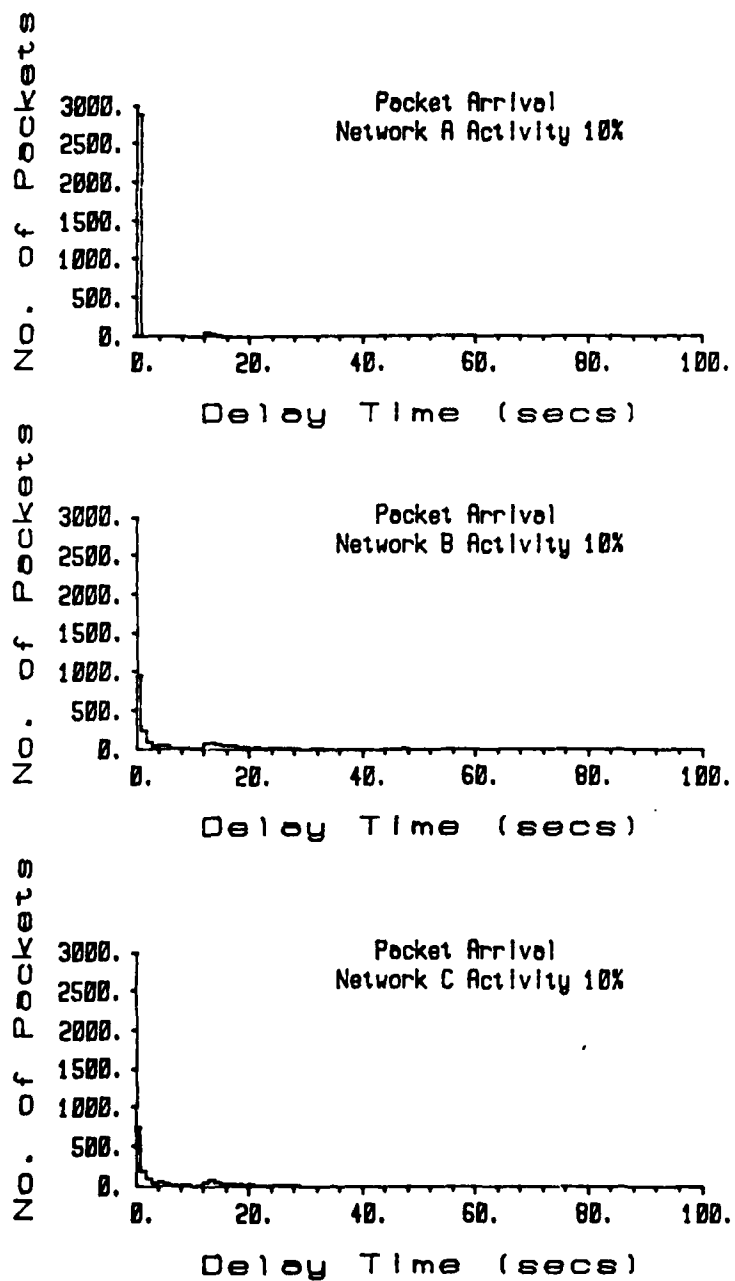


Figure 5

Acknowledgement Arrival Delay Periods

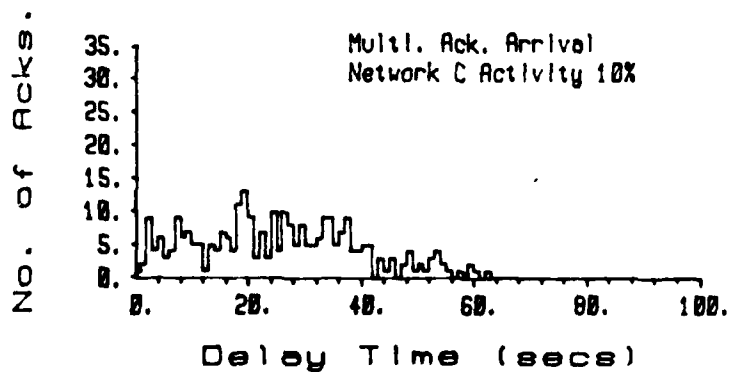
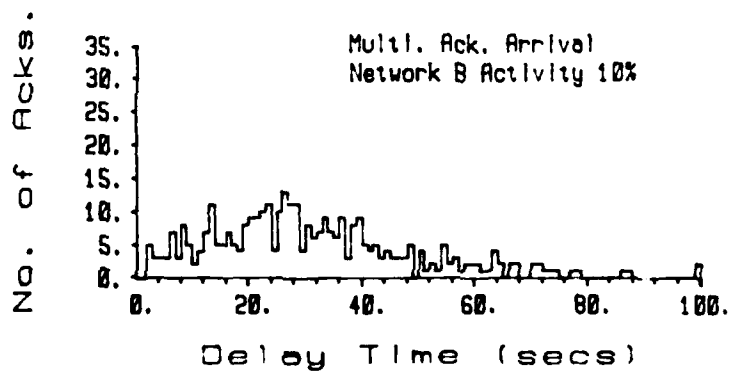
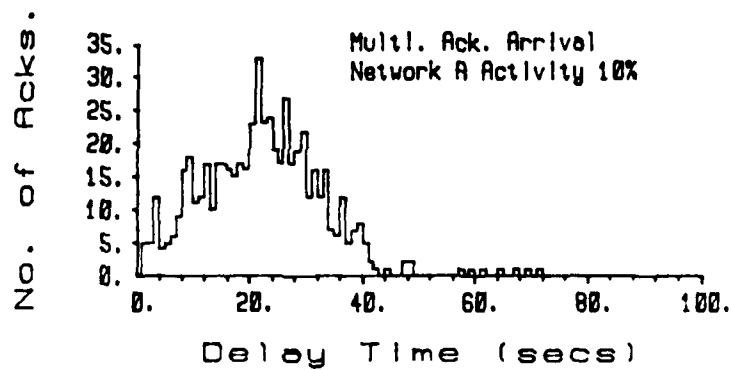


Figure 6

Packet Delivery Delay Periods

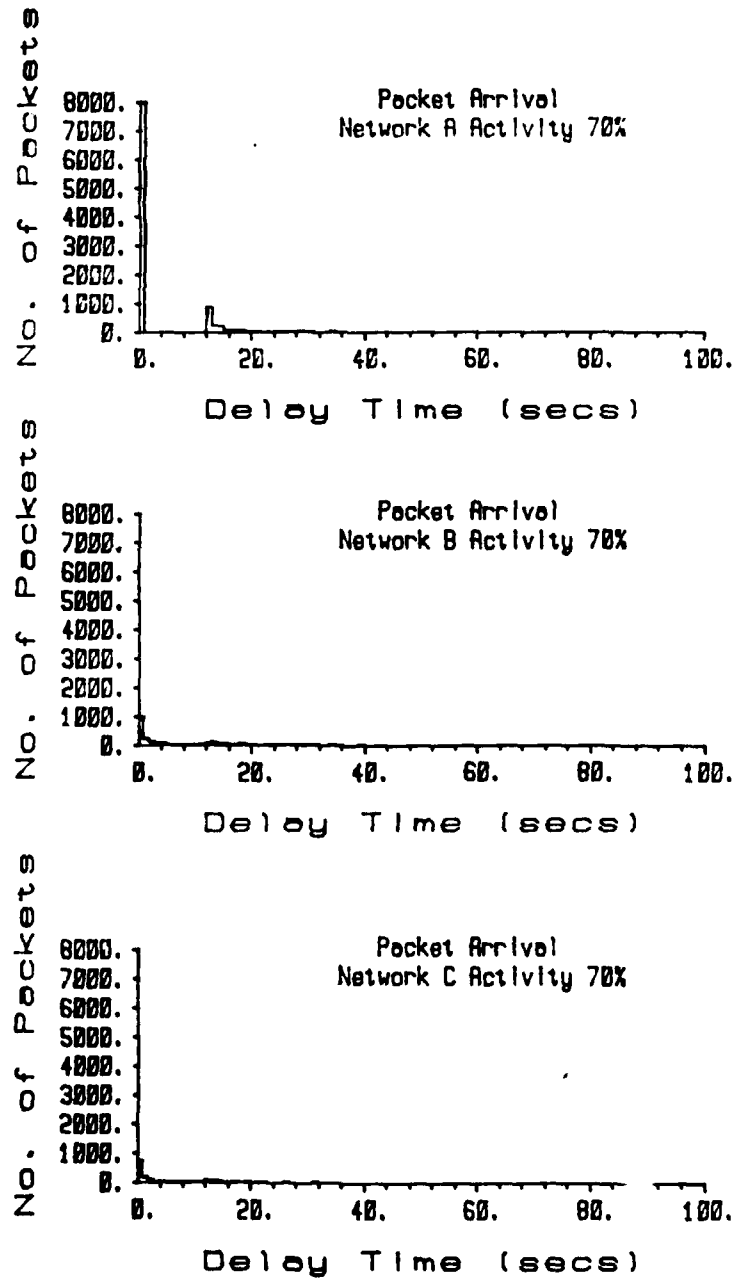


Figure 7

Acknowledgement Arrival Delay Periods

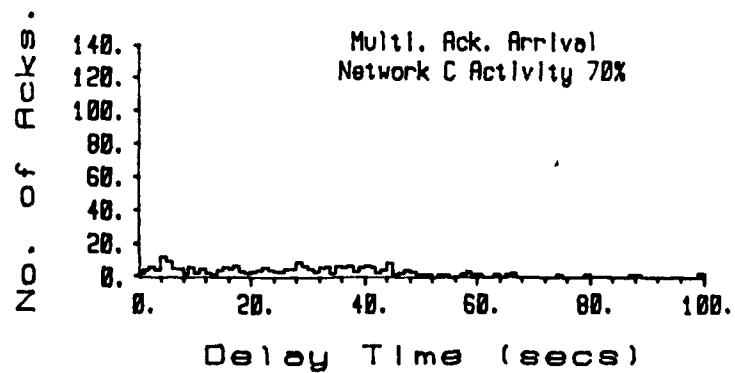
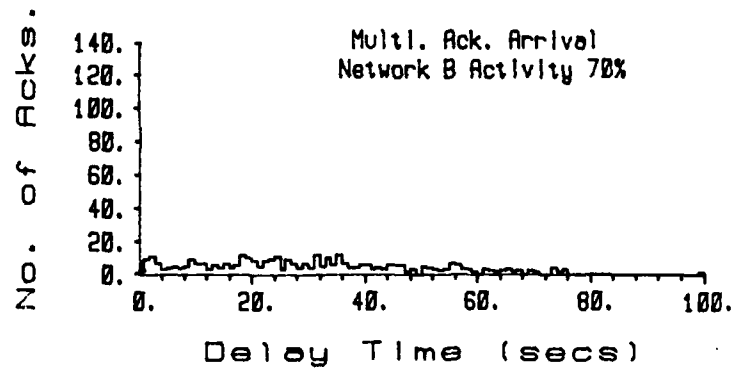
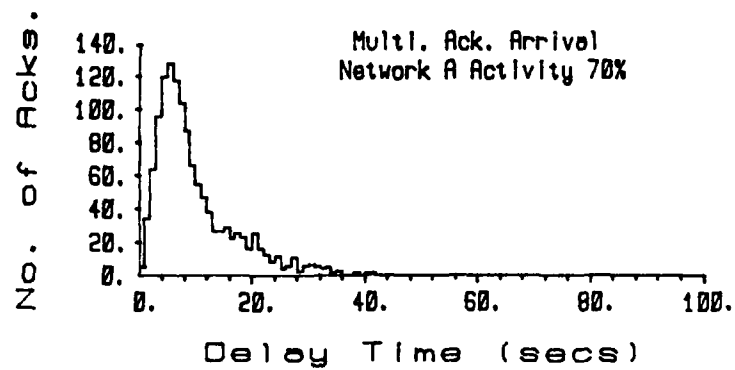


Figure 8

4. CONCLUSION

The RSRE Multicast Packet Radio Network Simulator has displayed improvements in the number of data packets delivered with the benefit of a reduction, in general, in the number of transmissions. The results generated by the modified simulation executed with a high level of activity display a significant improvement over those produced by the original node by node acknowledgement simulator. The increase in the throughput of data at the higher level activity is the reverse of that generally anticipated. The penalties being, an increase in the processing time required to fully analyse the received packet and an increase in the content of the packet header.

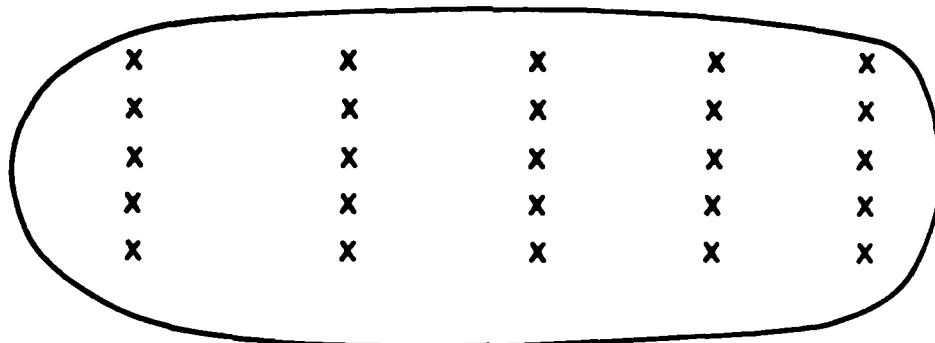
5. ACKNOWLEDGEMENT

The author wishes to acknowledge the assistance and guidance given by Dr. B.H. Davies, Head of Digital/Packet Radio section, CC4 division, with this implementation of his Multicast Protocol proposal on the Packet Radio Simulator.

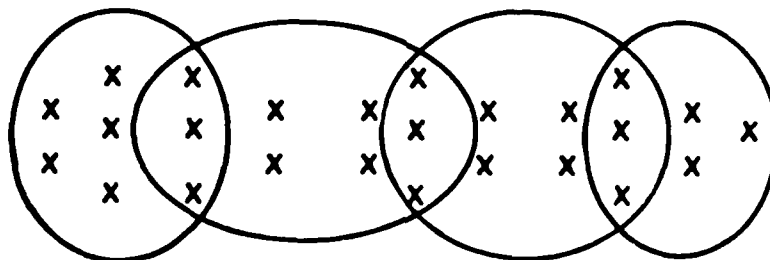
6. REFERENCES

- [1] HAZELL M.S. & DAVIES B.H., "A Fully Distributed Approach to the Design of a 16 Kbit/sec VHF Packet Radio Network", RSRE Report no. 84003, Feb. 1984.
- [2] SYLVIA SWAIN, "Adaptive Channel Access Algorithms for Narrow Band Multihop Packet Radio", RSRE Report no. 87012, Sept. 1987

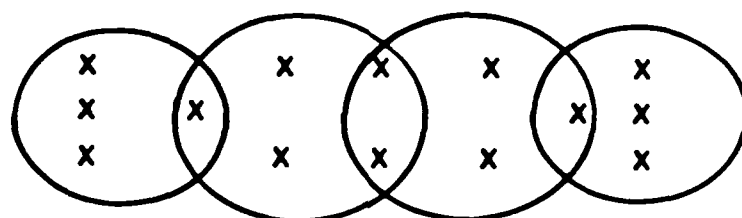
APPENDIX A



Group A



Group B



Group C

DOCUMENT CONTROL SHEET

Overall security classification of sheet UNCLASSIFIED

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