

Using DQRAP (Distributed Queueing Random Access Protocol) for Local Wireless Communications

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Abstract

Establishing voice circuits by transmitting voice packets, i.e., transmitting only when there is sound, has been studied for some 30 years. Despite the theoretical efficiency few such systems have been implemented, possibly because of the inadequacy of available multiple access protocols. A new protocol, DQRAP (Distributed Queueing Random Access Protocol), developed by Xu and Campbell at the Illinois Institute of Technology offers a level of performance which could make voice packet systems feasible. A model of a DQRAP-based voice packet system is presented along with results of simulation studies. The DQRAP simulation results are compared with simulation results of a PRMA (Packet Reservation Multiple Access) voice packet system. It is shown that under identical conditions and assuming a 32 Kbps source, DQRAP drops less packets than PRMA at all offered loads and supports close to two conversations per channel as compared to 1.6 conversations per channel supported by PRMA. A brief description of the DQRAP algorithm is included.

I Introduction

First generation cellular phone systems employ analog frequency modulation techniques to transmit information. FDMA is used as the multiple access protocol to share a radio channel in a cell amongst multiple users. Second generation cellular/cordless systems, now being deployed, utilize digital signal transmission techniques to both increase the utilization of available bandwidth and to provide more robust communications. The second generation cellular phone systems use a mixture of FDMA and TDMA as the multiple access protocol while the second generation cordless phone systems are using time division duplexing for two way communication [Goodman 91].

The periods of silence between voice utterances suggest that greater utilization of available bandwidth could be achieved by transmitting only when a voice packet was available. This phenomena has been utilized over the past thirty years in the main to better utilize expensive phone links such as use trans-oceanic cables. TASI (Time Assigned Speech Interpolation) is an example of such usage [Miedema 62]. Brady [65][68] studied human

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conversation patterns and discovered that people talk about 40% of the time during a conversation. Brady [69] developed a model for a speech encoder that could be made to simulate human speech. However, the lack of a suitable multiple access protocol limited the utilization of this phenomena in practical systems.

Goodman et al [88] and Goodman and Wei [89][91] developed a variant of the Reservation Aloha protocol, named PRMA (packet reservation multiple access), to support a voice packet communication system. Reservation Aloha is effective in supporting traffic patterns where once a station has a packet to transmit, there is a high probability that there will be more packets to transmit in succeeding frames [LAM 80]. Fortunately this is the general pattern of voice packets. The efficiency of a multiple access channel supporting voice transmission is established by setting a limit on the allowable delay for a voice packet. A packet exceeding the delay limit is dropped. A limit of 32 milliseconds delay and 1% threshold on dropped packets is used with both DQRAP and PRMA in evaluating performance. Goodman [91] has proposed PRMA for third generation cellular phone systems.

DQRAP was originally developed by Xu [90] as part of a directed research project to develop a multiple access protocol that would permit hundreds if not thousands of users to share a single data channel on a typical CATV cable system. DQRAP, however, has shown promise in a number of other environments and in this paper we present research results that suggest that DQRAP is suited for use in both third generation cellular phone systems and general purpose wireless data systems.

Section I reviews the research which established that voice circuits established by carrying information only when there is sound offer a theoretical advantage in performance. Section II shows the system configurations used in this study. Section III describes a variant protocol of DQRAP that supports almost twice the number of simultaneous conversations as does TDMA in a digital communication environment. The simulation results for both PRMA and DQRAP are presented in section IV. A discussion of these results is presented in section V and conclusions presented in section VI.

II System Configurations

The Goodman et al [88] model is used as a reference in assessing the performance of the DQRAP system. The PRMA and DQRAP system parameters and system configurations are shown in Table 1 and Figure 1 respectively. The system is simply a base station which can receive signals from an infinite number of terminal stations in its range. The terminals are transmitting information via the base station through a common channel which consists of either a single channel operating in half-duplex mode or two separate channels, one inbound to the base and one outbound from the base. The responsibility of the base station is to broadcast the result of the signals received from the terminals. A frame is used and consists of 20 slots each of which can carry a single packet. Each slot consists of 576 data bits and 64 control bits for a total of 640 bits. Stations receive the feedback about a slot from the base station before the next slot begins. PRMA follows the normal Reservation Aloha rule that if a station has a slot reserved it transmits in that slot as long as the station has something to send. A station which has packets to send and does not have a slot reserved transmits, if it has permission (explained below), a packet in the first available (empty) slot. If the feedback

indicates success then that slot is reserved for that terminal. The speech activity model used generate the simulated voice packets is identical to the model used by Goodman [89].

Definition	Notation	Units	Value	
			PRMA	DQRAP
Channel Rate	R_c	bits/sec	720,000	720,000
Source Rate	R_s	bits/sec	32,000	32,000
Frame Duration	T	secs	0.016	0.016/0.176
Overhead	H	bits	64	64/127
Maximum Delay	D_{max}	secs	0.032	0.032
Permission Prob	p		variable	NA
Conversations	M		variable	variable

Table 1. PRMA and DQRAP Variables

A station requiring permission to transmit generates a random number and if the number satisfies the probability requirement permission is granted. A station maintains the reservation as long as it is in the talk state and thus has packets to transmit. If a packet is not transmitted in two frame times, the packet is dropped, but the reservation acquisition process continues if there is another packet ready.

Gruber [81] points out that this delay limit has three important properties in a voice communication system. First, different delay limits will change the way conversation proceeds, changing the speech pattern. Second, the receiver has to compensate for packet delays in order to smooth the conversation. Thus, the delay dispersion must be limited to a certain range. Third, the delay is more perceptible between syllables than between words or sentences and this effect will cause intelligibility problems. The drop rate, obviously a factor of the allowable delay, should be less than 1% according to some studies.

Figure 1 also shows the configuration of the DQRAP system. Table 1 lists the parameters. The configuration is the same as for PRMA in that there is a base station serving terminals. Messages received at the base from terminals are relayed back to the terminals. The only difference is that the base station decodes the contents of minislots (explained later) and transmits as feedback in each slot the results of that decoding. The decoding by the base station is not mandatory, the incoming signal could be simply relayed to the terminals for decoding of the minislots. In DQRAP the slots are not organized into frames, each slot consists of 703 bits, corresponding to a PRMA slot plus 63 bits for three control minislots. The control minislot allocation in practice can probably be included in the 64 overhead bits of a PRMA slot but a conservative design is adopted.

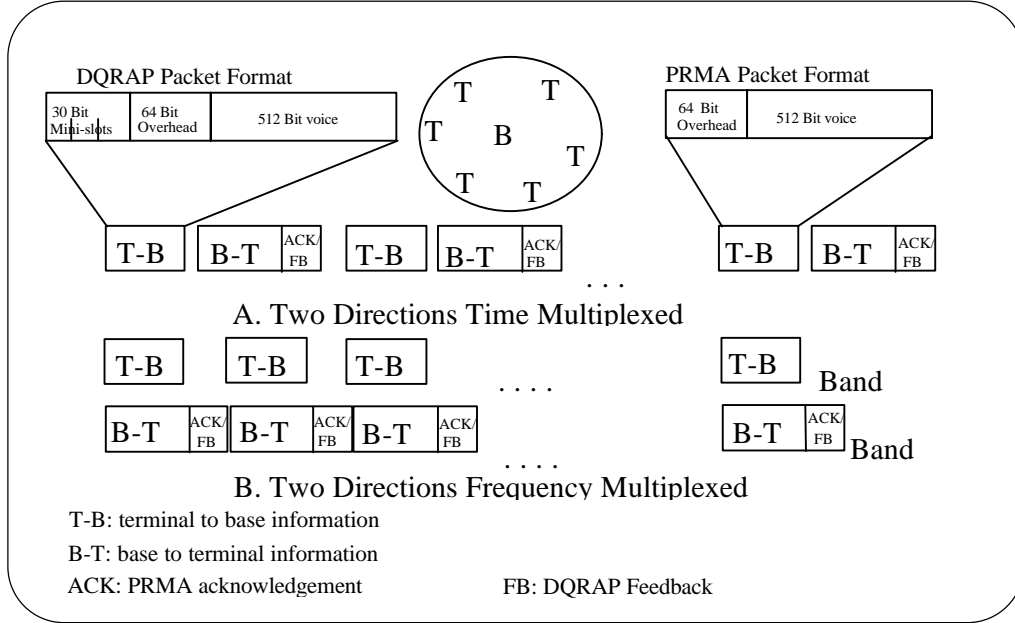


Figure 1. System Topology and Packet Format

III Description of DQRAP

DQRAP offers very good performance, in fact the performance with respect to both delay and throughput approaches that of ideal M/D/1 or M/M/1 systems depending upon whether fixed or variable length slots are used [Xu and Campbell 93]. The model used consists of a base and an infinite number of terminal stations. The basic transmission time is a slot which consists of a dataslot, which holds the packet, and m control minislots which are used to schedule transmission of the packets. In practice the number of minislots is 3. Terminals exchange information by transmitting in a control minislot and/or dataslot. The base station broadcasts the results of these received transmissions back to all the terminals.

DQRAP operates by providing two servers: a data server and a collision resolution server. Every station in the system maintains two queues: the collision resolution queue RQ, and the data transmission queue TQ. The TQ controls access to the data server (the data slots) while the RQ controls access to the collision resolution server (the minislots). A key requirement of DQRAP is that ternary feedback be provided to the terminals. This means that the base station must be able to distinguish between empty, successful, or a collision in a minislot and provide this feedback to the terminal stations. Bear in mind that TQ and RQ in practical implementations are simply binary counters.

A condensed set of rules is presented here. The reader is referred to Xu and Campbell [93] for a detailed description of DQRAP.

The two queues TQ and RQ assume either zero or non-zero (positive) values thus the protocol is described in terms of a four-state system.

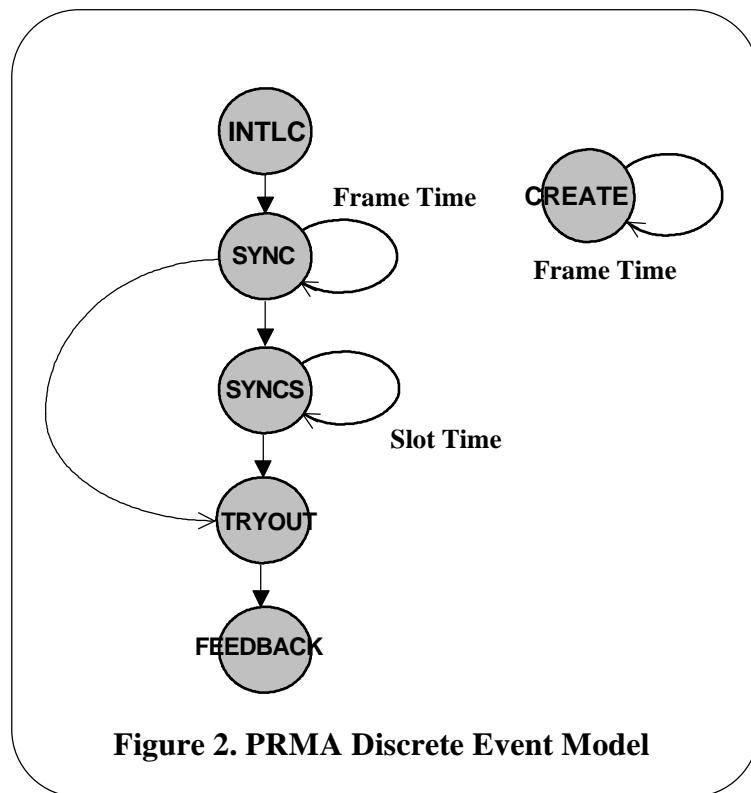
State 0 $RQ == 0$ and $TQ == 0$:

Every ready station transmits its packet in the dataslot and also transmits in one of the minislots (selected randomly). The feedback establishes one of three conditions:

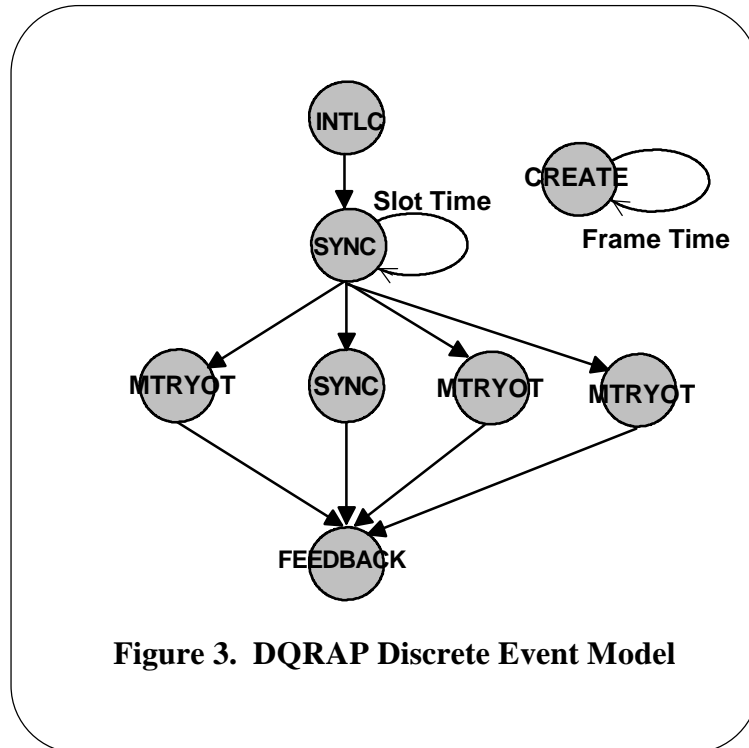
- (1) Only one station transmitted thus the data transmission is successful. Stay in state 0.
- (2) Two or more stations transmitted but each station transmitted in a different minislot. Go to state 1. TQ is incremented for each success.
- (3) Two or more stations transmitted and at least two stations transmitted in the same minislot. Go to state 2 or state 3 depending upon whether there are successful minislot transmissions.

State 1 $RQ == 0$ and $TQ > 0$:

A single station in the TQ is scheduled to transmit, therefore, the dataslot can be guaranteed collision free whenever $TQ > 0$. Each station already in TQ tracks its position thus knows when it is scheduled to transmit. Depending upon the feedback, the protocol can go to any of the four states.

**State 2** $RQ > 0$ and $TQ == 0$:

In this state, although $TQ == 0$, stations are not allowed to transmit packets in the dataslot. Those stations involved in the collision resolution process attempt to schedule transmission, i.e., move to the TQ , by using the minislots. Newly



arrived packets must wait until the collision is resolved, that is the system moves to the $RQ=0$ state, in order to make a reservation using the minislots.

State 3 $RQ > 0$ and $TQ > 0$:

A single station in the TQ is scheduled to transmit. The group (two or more) stations at the top of the RQ transmit in the minislots in an attempt to resolve their collision. Newly arrived packets must wait until the collision is resolved, that is the system moves to the $RQ=0$ state, in order to make a reservation using the minislots.

The maintenance of TQ is straightforward: TQ is incremented for each success in a minislot, is decremented for each data transmission when $TQ > 0$. The maintenance of RQ is more complicated. When $RQ=0$ the RQ is incremented for each collision. When $RQ>0$ then after each attempt to resolve a collision RQ is set to $RQ-1+N_{\text{collisions}}$. This formula reflects the fact that an attempt to resolve a single collision of say four stations could result in two new collisions of two stations each.

Figures 2 and 3 show the discrete event models for PRMA and DQRAP respectively. There are two features of DQRAP which help explain its performance.

- (1) The data transmission and collision resolution operations are essentially "decoupled". This is unique amongst the tree protocols to which DQRAP bears some resemblance.

(2) Xu and Campbell [93] show that if the algorithm describing DQRAP is followed and at least three minislots are used then a collision of multiplicity N will be resolved in less than N dataslots. A collision of multiplicity N means that N stations have arrived in an ETI (enabled transmission interval). This means that throughput will equal input up to a throughput of one.

Implementing the delay limit of voice packets in the DQRAP simulation is more complicated than when simulating PRMA. In DQRAP, a packet that is not transmitted immediately on arrival eventually acquires a reservation for some slot in the future and enters the transmission queue, TQ. There is a problem in that what if the station gets a reservation for some time in the future which could exceed the delay limit? Simply discarding the packet wastes channel capacity since all other stations assume that a packet will be transmitted in the reserved slot. Thus, the following packet dropping rule is added to the collision resolution rule:

IF (Wait_Time + minislot_selected + (TQ) > than the delay limit (measured in slots) then drop the packet.

For example, assume the delay limit is 40 slots. If a station, after waiting for the opportunity to transmit in a slot (Wait_Time), rolls a 2 when (TQ + Wait_Time) is equal to 39, the packet is dropped. This despite the possibility that the packet could still acquire position 40 by virtue of no other requests in the minislots. The discrete event diagram of the modified DQRAP is shown in Figure 3.

Conversations	Drop Rate	
	0% Overhead	10% Overhead
30	0	0
40	0.001	-
41	-	0.0066
42	-	0.0105
43	0.0038	0.0126
44	0.0038	0.0135
45	0.0068	0.0233
46	0.0094	-
47	0.0134	-
48	0.014	-
49	0.0246	-

Table 2: Drop Rate for DQRAP

IV The Simulation

SLAM II was selected as the simulation language because of easy modeling, embedded statistic and time advance function. Accordingly, the delays could be computed and collected. In the two simulations, the discrete event modeling approach is used.

The simulated speech generator continually generates voice packets while in the talk state. The active time of speech encoder follows an exponential distribution according to Brady [69]. This generator was used in both the PRMA and DQRAP simulations.

The simulation results are shown in Figures 4 and 5. Simultaneous conversations are plotted against the drop rate in Figure 4. The PRMA results agree with Goodman [88]. Figure 5 shows the performance for both systems with the number of conversations per subchannel plotted against the delay limit. Table 2 lists the drop rate for DQRAP for the cases of 0% and 10% overhead

V Discussion

In digital voice communication, the delay limit on the voice packet is an important factor in providing intelligible conversation at the receiver. Such a limit affects the design of any MAC protocol. Basically, PRMA is a variant of R-Aloha; thus, the longer the number of consecutive voice packets, the higher the channel utilization. But the first packet of a sequence must pay the conventional Slotted Aloha price with respect to delay. This property also implies instability when the system load is high. Even so, Goodman [91] shows that PRMA can support 1.6 conversations per subchannel, an impressive improvement over the 1 conversation supported using TDMA.

Xu and Campbell [93] show that DQRAP has a channel efficiency close to that of an idealized M/D/1 system, i.e., perfect scheduling when the source traffic follows Poisson distribution. An interesting question arose: was DQRAP suited for voice packet transmission which has a general traffic distribution? The results in Figure 5 show nearly 2.0 conversations per subchannel are supported using DQRAP as compared with 1.6 conversations per subchannel using PRMA. Significantly, no packets are dropped using DQRAP on loading below approximately 1.5 conversations per subchannel. PRMA drops packets at any load.

Another significant result is shown in Figure 5: DQRAP reaches close to its top capacity of two conversations per subchannel at a delay limit of 10 ms. PRMA supports slightly under 1.2 conversations at the 10 ms limit. This feature would be important where the packet voice access component was just one part of the overall transmission path. Figure 4 also shows that DQRAP with 0% overhead is close to G/D/1 performance in a voice transmission environment. Thus the answer to the question posed in the previous paragraph is in the affirmative: DQRAP performance can approach that of an idealized G/D/1 system.

An interesting implementation difference between PRMA and DQRAP is that PRMA must use a frame containing a number of slots. DQRAP is implemented using only the basic slot. A station transmits, following the DQRAP rules, in a slot and obtains feedback in the

next slot. Obtaining feedback about a slot before the next slot begins is ideal for DQRAP, in fact it is the "instantaneous feedback" so often assumed in theoretical papers.

We do not address implementation details but a comment on the one non-standard requirement facing the implementation of DQRAP, that of obtaining ternary feedback, is in order. The DQRAP simulations assume each minislot occupies the equivalent of 21 bit times,

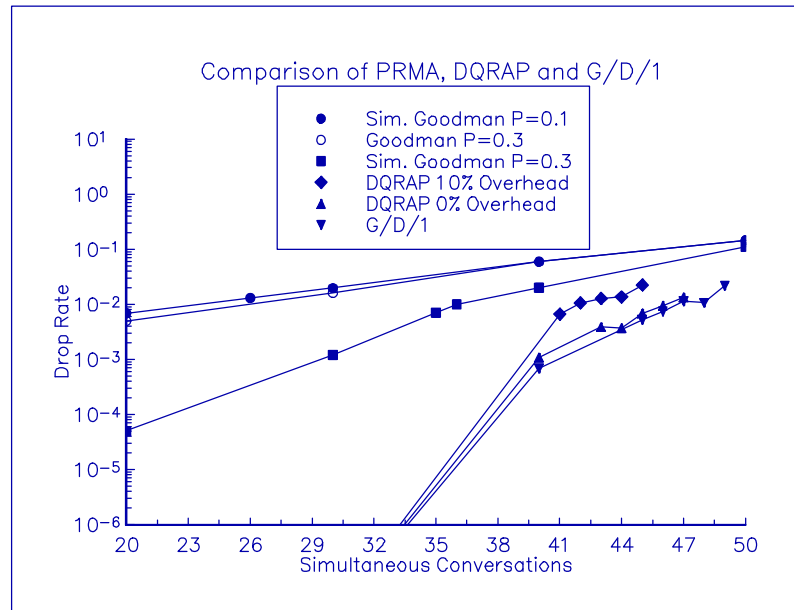


Figure 4. Drop Rate Comparison

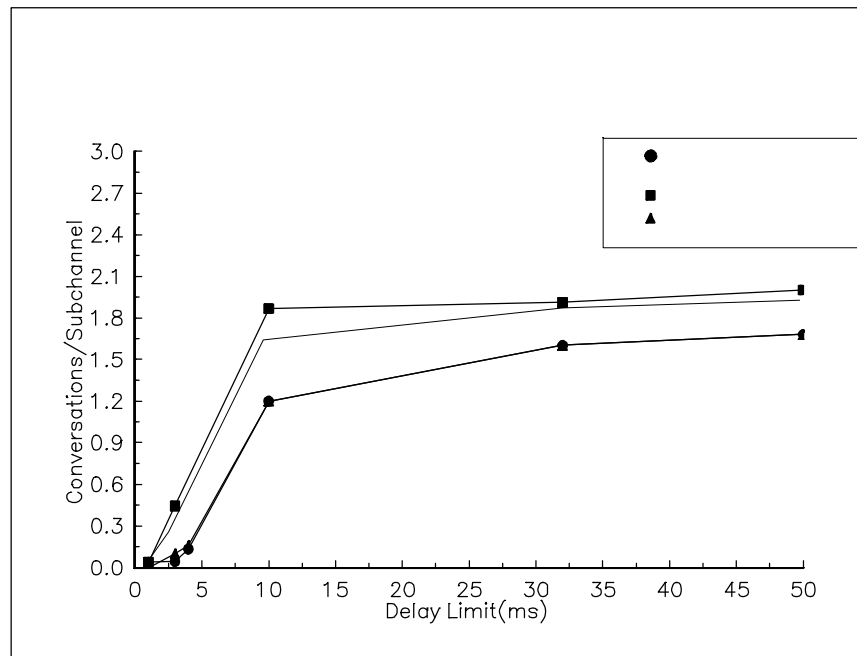


Figure 5. Conversations vs Delay Limit

a conservative estimate since theoretically a single bit could do the job. Practically speaking though, each minislot is a separate transmission by a station thus ramp-up and ramp-down for the signal take time and the detection of a collision, especially when modulated signals are used, is a non-trivial task. However ongoing research at IIT convinces us that in the voice packet environment the equivalent of some seven or eight bit times for a minislot would be adequate to enable the reliable detection of a collision. If this is possible the approximately 25 bit times required for the three minislots could possibly be part of the 64 bit overhead as already allocated for the PRMA packet. The DQRAP performance in a practical system could then approach the performance as shown in Figure 4 and Table 2 for the 0% overhead. Since only two bits are required for each minislot to carry the feedback to the stations, the remaining bit-times would be used for outgoing sync and status information.

VI Conclusions

It has been demonstrated that DQRAP provides a performance that approaches the ideal in a multiple access voice packet environment. We believe that this type of performance can be achieved in most wireless systems whether they carry voice, data, or a mixture of both. DQRAP should be given serious consideration as the multiple access protocol in all such systems.

References

- BRADY, PAUL T. 1965. "A Technique for Investigating On-Off Patterns of Speech", *The Bell System Technical Journal*, Vol 44, No. 1, pp 1-22.
- BRADY, PAUL T. 1968. "A Statistical Analysis of On-Off Patterns in 16 Conversations", *The Bell System Technical Journal*, Vol 47, No. 1, pp 73-91.
- BRADY, PAUL T. 1969. "A Model for Generating On-Off Speech Patterns in Two-way Conversation", *The Bell System Technical Journal*, Vol 48, No. 2, pp 2445-2472.
- GOODMAN, D. J., K. T. GAYLIARD, B. RAMAMURTHI. 1988. "Packet Reservation Multiple Access for Local Wireless Communications", *IEEE Vehicular Technology Conference*, Vol 40, No. 1, pp 701-706.
- GOODMAN, DAVID J., SHERRY X. WEI. 1989. "Factors Affecting the Bandwidth Efficiency of Packet Reservation Multiple Access", *IEEE Vehicular Technology Conference*, Vol 1, pp 292-299.
- GOODMAN, DAVID J., JACK M. HOLTZMAN. 1990. "Packet Communication Technology for Advanced Wireless Networks", *MILCOM '90*, Vol 2, pp 28.1.1-28.1.6.
- GOODMAN, DAVID J. 1991. "Trends in Cellular and Cordless Communications", *IEEE Communications Magazine*. Vol 29, No. 6, pp 31-40.
- GOODMAN, DAVID J., SHERRY X. WEI. 1991 "Efficiency of Packet Reservation Multiple Access", *IEEE Transactions on Vehicular Technology*, Vol 1, No. 1, pp 170-176.
- GRUBER, JOHN G. 1981. "Delay Issues in Integrated Voice and Data Networks", *IEEE Transactions on Communications*, Vol. 29, No. 6, pp 786-800, June.

- LAM, SIMON S. 1980 "Packet Broadcast Networks - A Performance Analysis of the R-ALOHA Protocol", *IEEE Transactions on Computers*, Vol C-29, pp 596-603.
- MIEDEMA, H. AND M. G. SCHACHTMAN. 1962. "TASI Quality-effect Speech Detectors and Interpolation", *Bell System Technical Journal*, Vol 41, pp 1455-1473.
- XU, WENXIN. 1990. "A Distributed Queueing Random Access Protocol for a Broadcast Channel", Ph.D. Thesis, Illinois Institute of Technology.
- XU, WENXIN and CAMPBELL, GRAHAM. 1993 A Distributed Queueing Random Access Protocol for a Broadcast Channel. *DQRAP Research Group Report 90-1*.