안정된 컴퓨터 통신망을 위한 임의 접근 프로토콜

이 상 건[†]

요 약

컴퓨터 통신망에서 안정된 프로토콜을 제공하기위해 분산된 큐를 이용한 임의 접근 프로토콜(Distributed Queuing Random Access Protocol:DQRAP)을 제안하고 검토한다. DQRAP 프로토콜은 통신망에서 노드간의 경쟁을 해소하고 메시지 전송을 스케줄하기위해 미니 슬롯을 사용해서 채널 피드백과 두 개의 분산 큐를 제공한다. 세 개의 미니슬롯을 사용할 경우 세 번의 미니슬롯이 피드백되어 도착했을 때 전송시간보다 빨리 충돌을 해결할수 있다. 세 개의 미니 슬롯을 사용한 모델링과 시뮬레이션을 통해서 DQRAP 프로토콜은 처리율과 지연에 대하여 M/D/1 시스템에 거의 근접하는 것을 알 수 있다. DQRAP 프로토콜은 안정되고 전파지연에 민감하지 않으므로 현재 사용중인 위성통신망, 근거리 통신망 (LAN) 혹은 메트로폴리탄 통신망(MAN) 등에 사용될 수 있다.

A Stable Random Access Protocol For A Computer Network

Sang-Keon Lee[†]

ABSTRACT

A near perfect stable random access protocol for a broadcast channel, the distributed queuing random access protocol(DQRAP), is presented and evaluated. The DQRAP protocol utilizes minislots to provide ternary channel feedback and two distributed queues to:(a) resolve contention and (b) to schedule the transmission of messages. Three minislots are sufficient to resolve collisions faster than the transmission times of all involved arrivals when ternary minislot feedback is used. Modelling and simulation indicate that the DQRAP protocol, using as few as three minislots, achieves a performance level which approaches that of a hypothetical perfect scheduling protocol, i.e., the M/D/1 system, with respect to propagation delay, thus offers the potential of improved performance over current protocols in satellite, metropolitan and packet radio networks.

1. Introduction

In the past two decades various random access protocols have been developed and applied to different types of multiaccess broadcast system, such as radio broadcast channels, satellite channels and local and metropolitan networks. Basically all random access protocols can be categorized into two families by the characteristics of the system stability. One is the ALOHA family of protocols, including the ALOHA, the slotted ALOHA, the CSMA, CSMA/CD and CSMA/CA protocols, which are well known and have gained wide application, but are unstable in nature[1]. Another is the tree family of protocols, or simply tree protocols, which are not as well known [2-4]. The first tree protocol was proposed by Capetanakis in 1977. Slotted channel is used, and

---

[†] 정 회 원:남서울산업대학교 정보통신공학과

논문접수:1996년 10월 4일, 심사완료:1997년 1월 7일

collisions are resolved by splitting involved transmitters in a binary tree structured network. Any subsequent arrivals are blocked for channel access while initial collision resolution is in progress. It achieves a maximum throughput of 0.43, and is stable for all input rates of less than 0.43[3]. The maximum throughput achieved by tree protocols without using minislots is 0.487 [4]. Collision is resolved in FCFS basis on the time of packet arrival by dynamically adjusting window size. The tree protocols that use control minislots(CMS) to obtain extra feedback can achieve higher throughput than those without using minislots[5-8]. Among them the announced arrival random access protocols[AARA] proposed by Towsley achieve the best performance with respect to throughput and delay characteristics [7]. The performance of AARA is related to feedback availability of data slot (DS), minislot (MS), and the number of minislots used. With three minislots the AARA protocol can achieve a throughput of 0.853. In general, contention resolution algorithms using minislots achieve better performance than alogorithms without minislots since more information about channel state is achieved. Minislot is a necessary overhead for faster contention resolution. However, to achieve throughput approaching one, the AARA protocol must use an infinite number of minislots. The AARA protocols do not achieve the bound of performance in this context.

We introduce a new stable random multiple access protocol, the distributed queuing random access protocol(DQRAP), for use in a broadcast channel shared by an infinite number of bursty stations. We observed that existing tree protocols use data slots to resolve contention thus reducing system throughput. Reducing or eliminating contention in the data slots would improve system performance. Implicitly, even though counters, etc. , are often used, there is a single queue in all tree algorithms. We achieve the desired performance by introducing an additional queue, the data transmission queue, to schedule data transmission parallel to the contention resolution queue. The minislots are used for contention resolution thus almost eliminating contention in the data slots. The DQRAP protocol, using as few as three minislots, achieves a performance level approaching that of a hypothetical perfect scheduling protocol, i.e., the M/D/1 system, with respect to throughput and delay.

2. Channel Model And Protocol

We consider a communication system serving an infinite number of bursty stations which communicate over a multiaccess and noiseless broadcast channel. The stations generate single messages of fixed length. The channel is divided into slots of fixed length. Each slot consists of m control minislots(CMS) followed by a single data slot(DS). The size of a data slot is assumed to be of length of one, equal to the length of messages generated by each station. Each CMS is assumed to be of length of δ. The size of δ is implementation dependent but δ is assumed to be much smaller than the data slot, i.e., $\delta \ll 1$. We take $(1+m\delta)$ as the channel time unit(CU). Assume that the generation times of the messages form a Poisson point process with intensity of λ messages per unit time. λ is also called input rate. A station may transmit a message in the data slot and/or a request in one of the control minislots. All stations can synchronize on both minislot and data slot boundaries and all stations can detect ternary feedback information for each minislot and data slot from the channel immediately after transmission. The assumption of immediate feedback is unrealistic, however, the collision resolution algorithms can be modified to accomodate delayed feedback[2].

The basic principle of the tree collision resolution algorithm is to resolve one initial collision before trying another one. Let t_{i-1} represent the instant in the transmission axis at which all messages arrived before instant of x_{i-1} in the arrival axis have succesfully resolved their conflict(Fig. 1). The interval (x_{i-1}, t_{i-1}) is called the waiting interval. The interval (x_{i-1}, x_i) is called the enable transmission interval(ETI), which is determined from the following formula:

$$x_i = x_{i-1} + \min\{W_0, t_{i-1} - x_{i-1}\}$$

where W_0 is the default window size which will be optimized by performance requirements. Obviously if the length of a waiting interval is greater than the default window size, the ETI is part of the waiting interval(see Fig. 1(a)), otherwise the ETI is equal to the waiting window(see Fig. 1(b)).

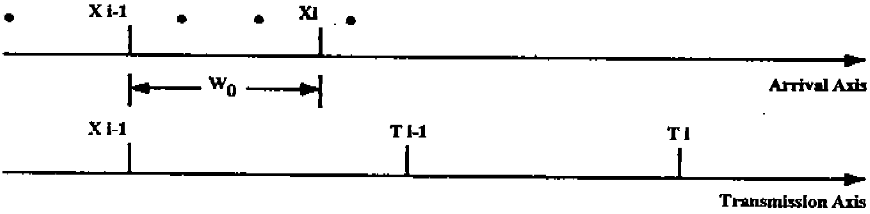
In the DQRAP protocol collision resolution is based on the ETI. Only when all messages in the current ETI have successfully resolved their conflicts, can the next ETI be initiated. Suppose at instant t_i all messages in the ETI (x_{i-1}, x_i) have successfully resolved thier conflicts, the interval (t_{i-1}, t_i) is called the contention resolution interval(CRI) corresponding to ETI (x_{i-1}, x_i).

In the DQRAP protocol two distributed queues are maintained by each station: the data transmission queue, or simply TQ, and the collision resolution queue, or simply RQ. $|TQ(t)|$ and $|RQ(t)|$ represent the queue lengths of the TQ and RQ at instant t respectively. The term "transmit a request" means that a station rolls an m-sided die and transmits a request signal in the minislot so selected. Let F_j, $j = 1, 2, \ldots, m$, denote feedback from the j-th minislot. F_j belongs to the set of {E, S, C}, where E denotes an empty minislot, S denotes the presence of a single request signal in a minislot, and C denotes the presence of two or more request signals transmitted in a single minislot.

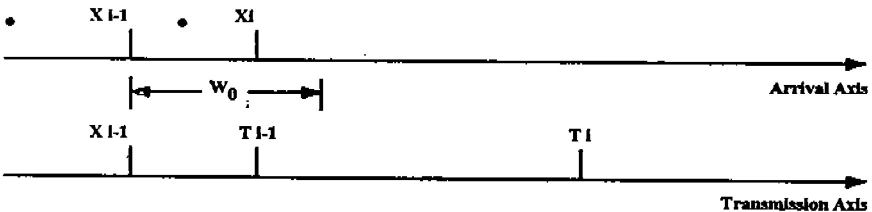
The protocol consists of three parts: data transmission rules(DTR), request transmission rules(RTR), and queueing discipline rules(QDR). FCFS(first come first served) scheduling discipline is used for both the TQ and the RQ but other scheduling disciplines could be utilized. Basically the DTR, the RTR and the QDR answer the questions: (1) who can transmit data and when? (2) who can transmit requests and when? and (3) how does the channel feedback affect the queues?

Data Transmission Rules(DTR)

(1)If ($|TQ(t)| = 0$ && $|RQ(t)| = 0$) then the stations with messages arrived in the current ETI transmit messages in the DS at (t).



(a) W0 <= T i-1 - X i-1



(b) W0 > T i-1 - X i-1

(Fig. 1) ETI and CRI

(2) If ($|TQ(t)|>0$) then the station which owns the first entry in the TQ transmits its message in the DS at (t).

Request Transmission Rules(RTR)

(1) If ($|RQ(t)|=0$) then the stations with messages arrived in the current ETI transmit requests at (t).

(2) If ($|RQ(t)|>0$) then the stations which own the first entry in the RQ transmit requests at (t).

Queueing Discipline Rules(QDR)

At time (t), using data slot or minislot feedback:

(1) Each station increments $|TQ(t)|$ for each ($F_j(j=1, 2,\ldots, m)=S$).

(2) Each station decrements $|TQ(t)|$ by one at (t) for a successful message transmission commencing at $(t-1)$.

(3) If $|RQ(t)|=0$ each station increments $|RQ(t)|$ by n where n is the number of collisions C in F_j, $j=1, 2,\ldots, m$.

(4) If $|RQ(t)|>0$ each station modifies $|RQ(t)|$ by $(n-1)$ where n is the number of collisions C in F_j, $j=1, 2,\ldots, m$.

(5) The stations which transmit successful requests or collided requests know their position in the TQ or the RQ and adjust their pointers to the TQ or the RQ accordingly.

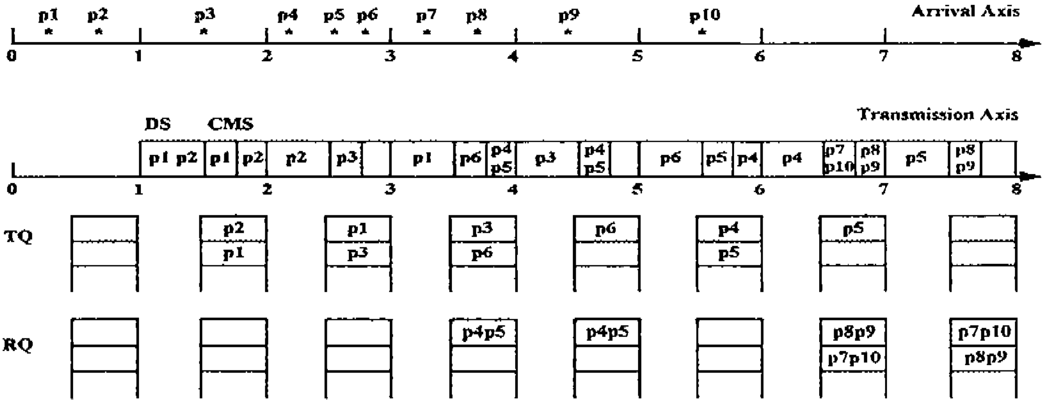
We assume that a station which has transmitted a request in a minislot enters into the TQ or the RQ in the order of minislot number from one to m.

Using the rules presented above the DQRAP protocol can be described by the following algorithm:

```
Set (t)=0, |TQ(t)|=0, and |RQ(t)|=0;
While (TRUE)
{
        1) t=t+1;
        2) transmit data obeying the DTR;
        3) transmit request obeying the RTR;
        4) All stations modify their counters of the TQ and RQ and their pointers to the TQs or the RQs following the QDR;
}
```

DTR (1) is important since it preserves the immediate access feature of random multiple access communications and distinguishes the DQRAP protocol from reservation protocols. DTR (1) may cause a collision on the data slot, but without DTR (1) improves delay characteristics of the protocol, especially when input rate is not very high.

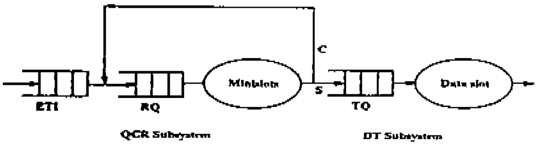
An example (refer to Fig. 2) is now presented to describe the operation of the DQRAP protocol. In



(Fig. 2) An Example of the DQRAP Protocol this example the default window size is infinity ($W_0 = \infty$), i.e., the ETI is equal to the waiting interval. The time axis is divided into equal slots with length of one channel unit. Above the time axis the counters of the CMS(control minislots) and DS(data slots) are shown. Below the time axis the contents of the TQ and the RQ at each station are shown. The symbol "*" denotes the arrival time of messages p1, p2,..., p10. In this example two minislots are used. Assume at $t=0$ that both the TQ and RQ are empty. At $t=1$, p1 and p2 each transmit both requests and messages. At $t=2$, the feedback shows that the p1 and p2 data messages have collided but not their requests. p2 and p1 go into the TQ and p2 data is transmitted at $t=2$. Meanwhile p3, arriving in interval [1, 2), transmits a request, but no data since $|TQ(2)| > 0$. p3 enters the TQ as p2 leaves. While p1 and p3 are waiting their turn to transmit data, p4, p5 and p6 transmit requests at $t=3$. p6's request is okay and p6 enters TQ but p4 and p5 collide and thus enter the RQ. p4 and p5 collide at $t=4$ on their first try to resolve the collision but on the next attempt at $t=5$ they succeed and enter the TQ, their order determined by their relative position in the minislots. p6 transmits at $t=5$ since the TQ operates independently of the RQ. The RQ is empty at $t=6$ thus p7, p8 and p9, which had arrived in the interval [3, 5) and could not transmit requests or data join p10 at $t=6$ in making their first try to transmit. p8 and p9 collide in the first minislot while p7 and p10 collide in the second minislot. This etermines their order in the RQ. The process continues.

3. Modeling and Evaluation

The DQRAP protocol can be modeled as a queueing system that consists of two subsystems: (1) a queueing contention resolution subsystem(QCR), and (2) a data transmission(DT) subsystem (Fig. 3), if DTR(1) is not considered. The QCR subsystem can be evaluated by the Markov chain theory. The DT subsystem can be modeled as a G/D/1 queue. It is obvious that including DTR (1) rule improves the delay characteristics of the system, but does not decrease the system throughput.



(Fig. 3) Modeling of the DQRAP Protocol

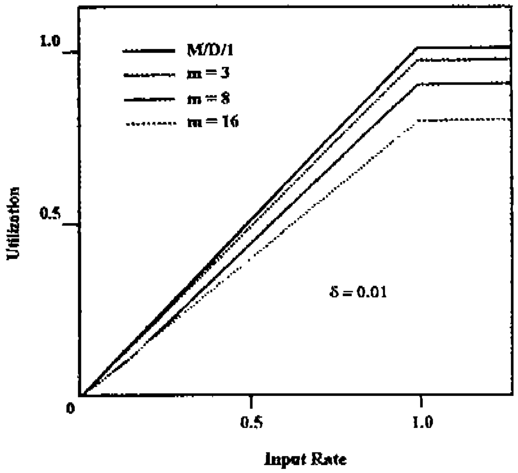
It can be proved that for a given input rate, the QCR subsystem is stable, if the average length of the CRI is less than the average length fo the ETI. From this the maximum input rate at which the QCR subsystem remains stable for a given number of minislots can be obtained. ⟨Table 1⟩ shows the results of this calculation.

The performace of the DQRAP protocol is determined by the QCR subsystem and the DT subsystem. The QCR subsystem is stable even when the input rate is greater than one if three or more minislots are utilized. Thus the system throughput is entirely determined by the DT subsystem. That is, the DQRAP protocol can achieve a theoretical throughput approaching one and is stable for all input rate less than

⟨Table 1⟩ Maximum Input Rate and the Corresponding Window Size as a Function of the Minislot Number.

m	max input rate	window size	m	max input rate	window size
2	0.8590	2.642	10	2.4891	2.520
3	1.2400	2.794	11	2.6063	2.483
4	1.5156	2.835	12	2.7171	2.442
5	1.7353	2.799	13	2.8226	2.425
6	1.9207	2.726	14	2.9234	2.409
7	2.0834	2.670	15	3.0201	2.376
8	2.2299	2.611	16	3.1133	2.363
9	2.3642	2.552			

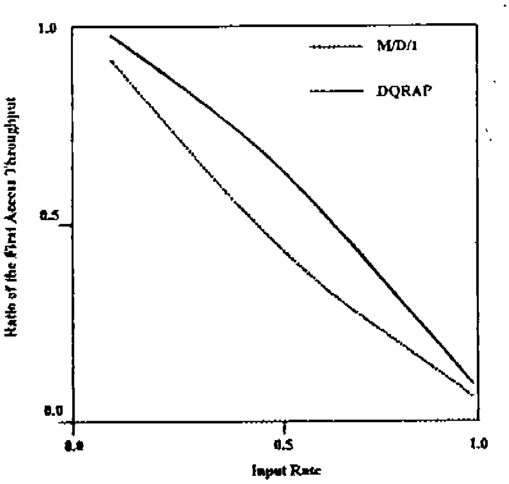
one, if three or more minislots are utilized. (Fig. 4) shows the throughput of the DQRAP protocol as a function of the input rate and the minislot number with the total minislot overhead equal to 0.01.



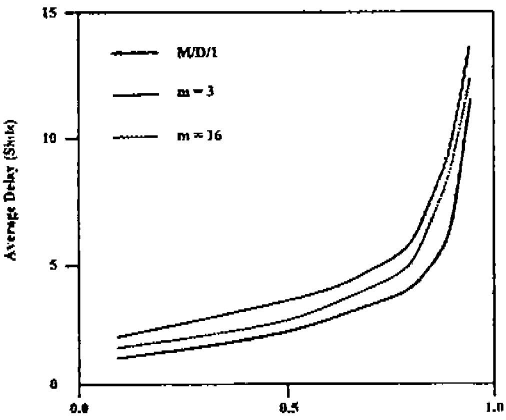
(Fig. 4) The Throughput Characteristics of the DQRAP Protocol

4. Numerical Results and Comparisons

Simulations have been carried out to evaluate other characteristics of the DQRAP protocol using the SLAM II simulation package. The performance bound of all random access protocols for a slotted broadcast channel shared by an infinite number of Poisson source is that of a hypothetical perfect scheduling protocol, i.e. the M/D/1 system. Thus the performance of the DQRAP protocol is best demonstrated by comparison with that of the M/D/1 system. (Fig. 5) shows the immediate access characteristic of the DQRAP protocol by comparing the percentage of its first access throughput, which is defined as the throughput of successful transmission of messages in the first slot after its arrival, with that of the M/D/1 system. (Fig. 6) compares the delay characteristics of the DQRAP protocol with the M/D/1 system. (Fig. 6) also shows that increasing the number of minislots does not dramatically improve the delay characteristics. For most practical purpose the number of minislots need not be greater than three. The simulation also shows that the performance of the DQRAP protocol is not sensitive to the window size. This result suggests that to simplify the DQRAP protocol using the infinity of window size is appropriate, that is, all blocked stations are allowed to transmit their requests or data as soon as the RQ becomes empty.



(Fig. 5) First Access Throughput of the DQRAP Protocol



(Fig. 6) Delay Characteristics of the DQRAP Protocol

To achieve a theoretical throughput approaching one the announced arrival random access protocols require an infinite number of minislots, but the DQRAP requires as few as three minislots. Using three minislots the announced arrival random access protocols achieve a throughput of 0.853. The DQRAP protocol provides a better performance than the best tree protocols to date.

5. Conclusion

The above analysis and the example demonstrates that the DQRAP protocol achieves a performance level approaching that of a perfect scheduling protocol, i.e., the M/D/1 system. The DQRAP protocol provides fairness in that every arrival in an ETI is guaranteed service before any arrivals in a subsequent ETI. In fact if the arrival time in the ETI is used to select the CMS, the DQRAP protocol could provide any degree of ordering desired. The DQRAP protocol is stable at all input rates less than one when three or more minislots are utilized. The DQRAP protocol can be implemented by overcoming the usual problems attendant with any medium access control method. Ternary feedback using the CMS probably offers the greatest challenge. However many existing satellite protocols utilize the concept of minislots thus the challenge is more to reduce the overhead due to the size of the CMS.

A multiple access protocol which would permit thousands of users to randomly access the medium was required. The specific goal is the utilization in a tree-and-branch topology of the distributed queueing concept of DQDB [10]. The DQDB protocol can be use in satellite, metropolitan, radio packet and local area networks.

References

[1] F. A. Tobagi, "Multiaccess Protocols in Packet Communication Systems," IEEE Trans. on Communication., COM-28, No. 4, pp. 468-488, Apr. 1980.

[2] J. L. Massey, "Collision Resolution Algorithm and Random Access Communications," in Multiple Communication System, G. Longo Ed. New York: Springer-Verlag, 1981. pp. 73-137.

[3] J. I. Capetankis, "Tree Algorithm for Packet Broadcasting Channel," IEEE Trans. Inform. Theory, Vol. IT-25, pp. 505-515, Sep. 1979.

[4] R. G. Gallager, "A Perspective on Multiaccess Channels," IEEE Trans. on Information Theory, Vol. IT-31, No. 2, pp. 124-142, Mar. 1985.

[5] L. Merakos and D. Kazakos, "Multiaccess of a Slotted Channel Using a Control Mini-Slot," in Proc. Int. Conf. Comm. 1983, pp C5.3.1-C5.3.6.

[6] J. C. Huang and T. Berger, "Delay Analysis of Interval Searching Contention Resolution Algorithm," IEEE Trans. on Inform. Theory, Vol. IT-31, No.2, pp. 264-273, Mar. 1985.

[7] T. Towsley and P. O. Vales, "Announced Arrival Random Access Protocols," IEEE Trans. Comm. Vol. COM-35, No. 5, pp. 513-521, May 1987.

[8] Y. Oie, T. Suda, H. Miyahara, and T. Hasegawa, "Throughput and Delay Analysis of Free Access Tree Algorithm with Minislots," IEEE Trans. on Comm. Vol. COM-38, No. 2, pp. 137-141, Feb. 1990.

[9] S. Sirazi, "TrIInet-A Demand-Adaptive Medium-Access Protocol for Metropolitan Area Networks," Ph.D. Dissertation, Illinois Institute of Technology, 1986.

[10] R. M. Newman, Z. M. Budrikis and J. L. Hullet, "The QPSX Man," IEEE Comm. Magazine, Vol. 26, No. 4, pp. 20-28, Apr. 1988.

이 상 건

1985년 경북대학교 전자공학과 졸업(학사)

1992년 Illinois Institute of Technology 대학원 Computer Science 졸업(석사)

1993년~현재 Illinois Institute of Technology 대학원 Computer Science(박사과정)

1985년~1991년 삼성전자 Computer부문 중형 컴퓨터 개발실(주임 연구원)

1995년~현재 남서울 산업대학교 정보통신공학과 전임강사

관심분야: 데이터 통신 및 Real-Time System Scheduling