CONTENTION CONTROL IN MULTI-ACCESS RESOURCE SYSTEMS
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ABSTRACT

All wireless communications, including radio, satellite, and mobile systems, as well as wired broadcast networks, require mechanisms for resolving contention. Strategies for allocation of shared bandwidth among competing users have evolved from no policy (e.g., ham radio, where strength of signal determines access), to complex control and encoding schemes, where access is provided based on varying scheduling goals such as throughput, priorities, bounded waits, and fairness (i.e., DQDB). As wireless media become more heavily used, mechanisms that prevent contention (e.g. TDMA) at a significant cost of bandwidth are balanced against mechanisms that allow contention to occur, but, at their own cost, recover from it (e.g., IEEE 802.11). We review the various types of protocols for contention control in multi-access resource systems to aid in the understanding of why they have evolved and under which conditions they have been successful.

1. INTRODUCTION

Assume that three 20 mph car ramps merge into one 70mph lane, an example of Time Division Multiplexing (TDM). How can we assure that cars are given fair access to the merged lane and that cars do not collide when contending for the road? We could rely on drivers to "sense" the traffic conditions, but if sensing is imperfect, this media access method may cause collisions. We could install traffic lights, so that each ramp is allocated the same amount of time for merges. Traffic lights implement a multi-access protocol, Time Division Multiple Access (TDMA), which prevents collisions if drivers adhere to it. Alternatively, we could widen the merged road into three lanes with barriers between them, so that each of the ramps feeds into exactly one lane. This method is similar to Frequency Division Multiplexing (FDM). TDMA and FDMA are access protocols that prevent collisions, but may waste resource slots. Network protocols have been developed to try to better utilize resources during non-uniform traffic conditions.

Although cars are the unit of transfer, they are usually employed to facilitate transporting humans. Similarly, frames, which are the unit of transfer in multi-access protocols, enclose messages for delivery. Messages, however, are usually broken up, so that several frames are required for each message. As an additional point of differentiation, communication systems typically are more willing to allow collisions than vehicular systems.

2. DEFINTIONS AND ASSUMPTIONS

A multi-access communication system consists of three components:
1. A set of at least two independent stations, each of which has a set of messages to deliver to one or more stations in the system.
2. A communication line on which the messages are sent.

3. A multi-access protocol that manipulates the messages and maps them onto the communications line over discrete and potentially unbounded intervals of time.

We basically accept the properties of a multi-access communication system given in Kurose et al. [12] in order to introduce general principles. Some variations that are widely used, however, are included in our discussion.

1) Stations are asynchronous and can transmit at any time interval unless restricted by the access protocol. There is no global clock, but synchronization between stations can be achieved using the shared communication line. Any station's information about the state of the system is obtained from the channel and is thus delayed by the propagation time that it takes for the information to reach that station. Each station receives messages from its user(s), perhaps divides them into packets and attaches control bits to form frames, then stores the frames in its buffer. A frame is considered to be an indivisible unit of transmission, so that if a broadcast must be resent for any reason, the minimal unit of repeat is a frame. We assume that each station is blocked until it completes transmission of each frame, and, depending on the protocol, perhaps until it receives an acknowledgement. Protocols that require an acknowledgment will cause a time-out and retransmission if an acknowledgment is not received. Acknowledgements are omitted in some protocols, perhaps because the media is reliable or because discarding of some frames is preferable to a delay. Acknowledgments serve important functions besides the control of transmission errors, such as confirming access to the channel. Frames that are received correctly by the destination station(s) are stored in the destination's buffer so that they can be reassembled into their message and delivered to the user.

2) The communication line supports broadcast transmission, so that stations generally receive all frames. Some hardware, e.g., intelligent hubs, repeaters, bridges, and/ or switches, restrict delivery to segments of the network. In addition, in wireless networks some stations may be outside the range of the transmission. The communication line may be wired, such as twisted pair, or wireless, such as a packet radio channel. The line may be a broadcast media, such as broadband coaxial cable, or a point-to-point media, such as fiber. Stations may have access to a single channel or to multiple channels. Overlapping transmissions may be completely destroyed or salvageable.
a) According to the properties assigned by Kurose, et al. [12] for purposes of their analysis, all stations use a single channel for gaining access and then transmitting data frames. For wireless media, however, typically two channels are required for uplink and downlink (outbound and inbound) traffic. In addition, many media access protocols use multiple channels (e.g., WDMA, FDMA, and FHMA) and these technologies are included in this paper.
b) According to the properties assigned by Kurose et al. [12], any frames that overlap on the channel are destroyed. This property requires that hardware be the same for all wired stations so that their signal strength is the same. For wireless systems, a station with higher transmission strength or one that is close to the repeater may overpower conflicting signals (the capture effect). For example, Aloha with Capture effect (C-Aloha) specifically assigns different level signals to increase the potential throughput of an Aloha system [16]. In addition, Code Division Multiple Access (CDMA) is becoming increasingly popular in wireless systems today, for reasons that include the multi-path phenomenon (a signal radiates in different directions, with results arriving at slightly different times), its anti-jamming attributes, and security

considerations. Using CDMA, stations broadcast their codewords onto a shared channel simultaneously, but the receivers can separate and identify individual transmissions. Extra bandwidth is required, however, so that codewords are long enough to provide orthogonality for all participating stations.

3) A multi-access protocol is a set of rules agreed upon by all stations for partitioning the channel into time or space intervals for the transmission of the frames. It serves as a traffic monitor, so that stations utilize the shared media effectively. We assume that time is partitioned into very small discrete units, and that an access protocol may bind sets of contiguous time units into larger intervals of time. If stations agree upon fixed, coordinated time intervals, these are called slots. The protocol is decentralized so that
a) Stations obtain knowledge of the state of the system only through the shared channel; this knowledge is essential for access coordination.
b) There is no single station whose failure will cause the failure of the entire system.

3. GOALS OF A MULTI-ACCESS PROTOCOL

Goals of a multi-access protocol include:
1. Maximized throughput
2. Minimized response time
3. Priority allocation, with fairness within the priority classes.
4. Stability (i.e., bounded response times)
5. Satisfaction of real-time constraints, including predictability (no jitter)
6. Simplicity, resiliency, scalability, reliability, availability and maturity
7. Interoperability
8. Minimized cost

4. CLASSIFICATION OF CHANNEL ALLOCATION PROTOCOLS

We identify three types of channel allocation methods in multi-access protocols, which are further subdivided:
1) Fixed assignment protocols restrict data transmission for a fixed population of stations to predetermined time intervals and/or frequencies.
2) Random access protocols allow stations to transmit without deference to other stations. Where stations have no knowledge of the state of the channel, they transmit completely asynchronously, as soon as they receive a message from their user and form a frame. If they are able to sense the channel, they refrain as long as they sense ongoing transmission. If they are able to receive synchronizing signals, they may be restricted to broadcasting at the beginning of a slot.
3) Dynamic allocation protocols assign time intervals for data based on current traffic conditions. We identify:
a) Three types of contention-free dynamic channel allocation schemes, in which a small amount of bandwidth is pre-allocated for contention-free control slots that determine (larger amounts of) bandwidth allocation for data on demand.

     (1) In polling systems, a controller sends polls to each station in turn asking for data to transmit. Stations transmit data only following receipt of a poll.

(2) In token passing systems, the poll is called a token, and stations pass the token and any data among themselves in a round robin station order.

(3) In reservation systems, stations use fixed time intervals to enter reservations for dynamically allocated data transmission slots.

b) Three types of contention-based dynamic channel allocation: These hybrid protocols alternate between contention-free and contention based mechanisms at different stages of the access process.

(1) In initial fixed-assignment schemes, stations are allowed to contend for unused slots.

(2) In initial random access schemes, random access is used for reservations for dynamic assignment of fixed bands.

(3) In initial random access schemes, when contention or perhaps repeated contention occurs, the protocol alternates to a contention-free scheme.

4.1 FIXED ASSIGNMENT PROTOCOLS

In fixed assignment protocols, the channel is statically partitioned into a fixed number of units. In Time Division Multiple Access (TDMA), sets of round-robin time slots are assigned, and in Frequency Division Multiple Access (FDMA), the frequency spectrum is partitioned into separate bands. Bandwidth is pre-allocated for a fixed set of stations' data transmission. Each data unit's station is identified by its position in the data stream, thus reducing control overhead and providing simplicity and efficiency. Fair channel allocation is obtained, with a separate (possibly logical) channel assigned to each station. These synchronous systems assure control over average and worst case delay for voice and video traffic. Throughput is optimal during heavy traffic when all capacity is being utilized, due to low overhead and contention-free transmission. Obviously, fixed assignment systems provide less flexibility for data traffic, as long bursts of data must be stored waiting for some channels, while other channels are unused. In particular, for non-uniform traffic conditions, capacity that is not used is wasted, while long queues develop for access to busy channels. Results from queueing theory state that systems with multiple queues for multiple servers, as in fixed assignment protocols, engender longer delays [20] and lower utilization than single queue systems. These methods require careful synchronization with some cost in bandwidth (perhaps 30 -50 microsecond guard bands in TDM and 600Hz guard bands in FDM). An additional disadvantage of fixed assignment schemes is that they are not scalable; new stations cannot be added dynamically to the station set - it might not be feasible to add them even if a network were brought down temporarily.

FDM was implemented for radio communications in 1910, and for wired communications by Bell Laboratories in 1918 between Baltimore and Pittsburgh [4]. The telephone network used FDM for circuit switching and analog transmission since the 1930s. During the 1940s to 1960s, as mobile telephony was being developed, only limited FDM bands (initially 11 channels in the 40MHz band) were allocated. Blocking and high costs were rampant. To obtain bandwidth, each handset searched the frequency spectrum assigned to cellular phones, looking for an idle FDM channel. Cellular analog systems were developed at Bell Laboratories with the reuse of radio frequency bands in different cells of the cellular structure. The first modern cellular (analog) system, the Nordic Mobile Telephone System, went into commercial operation in Sweden in 1981. Cellular analog systems, such as Advanced Mobile Phone System (AMPS), which was commercially available by 1983, became increasingly popular, due partially to the decrease in size and weight of the handset. Global

System for Mobile Communications (GSM), a digital cellular system, was developed by 1982 in Europe [17], with recent efforts to define interfaces between it and Personal Digital Cellular Communications (PDC). Cellular carriers are assigned frequency bands by organizations such as the FCC. These bands (or portions of them) are then allocated to users on demand.

Time Division Multiplexing (TDM) was used in telegraph systems in the late 19th century. In1957 Bell Laboratories developed the T1 carrier, which was implemented by 1962. This digital wired transmission system converted analog voice to digital form using PCM, and used TDM for multiplexing 24 input lines, with 8 bits allocated on the output frame for each input line. There are many advantages of TDM over FDM. Systems can take advantage of the lowered costs of digital technology, digital signaling is possible with TDM, where the absence of intermodulation effects allows for better line utilization. By the 1980s, AT&T had replaced all of its analog multiplexing equipment with digital multiplexing lines. TDMA was adopted as an industry standard with Digital Autonomous Terminal Access Communications (DATAC) (1983-88), a joint program between NASA and Boeing that controlled access for onboard computer networks between aircraft electronic flight systems. EIA has established an Intermediate Standard (IS-54) for TDMA, with 30kHz bands divided into 3 or 6 time slots. GSM uses 200 kHz bands, with 8 full rate or 16 half-rate time slots. AT & T Wireless services and Southwestern Bell Wireless also rely on TDMA.

In 1880, Alexander Graham Bell invented the photophone for the transmission of sound on a beam of light for a distance of over a hundred meters. Prototypes of optical fibers that were suitable for transmission were developed at Corning Glass Works by 1970. By 1977, GTE installed optical fiber commercial systems. By the 1980s, WDM was available for fiber. Optical fiber is currently the backbone media of the telecommunications industry, with Wavelength Division Multiple Access (WDMA) providing efficient utilization of the enormous bandwidth available through fiber.

Spread spectrum transmission was patented in 1941 by Hedy Lamarr and George Antheil for military purposes. Ms Lamarr recognized the potential security inherent in transmitting (to torpedoes) over different parts of the frequency spectrum as determined by a pseudo-random pattern known to the sender and receiver. Although the military did not develop this technology at that time, spread spectrum or Frequency Hopping Multiple Access (FDMA) has been recently combined with CDMA for many wireless applications, particularly Low Orbiting Satellites (LEOs).

Fixed assignment schemes remain the major technology behind AM and FM radio broadcasting, as well as satellite television systems. They are combined with other mechanisms to obtain bandwidth on demand.

4.2 RANDOM ACCESS PROTOCOLS

Random access protocols allow stations to broadcast without direct consideration of other stations in the competing station set. Channel access is randomly determined. Stations are ready to broadcast as soon as they receive a message from their user. If they can sense the channel, they can refrain from interfering with current transmissions. Collisions occur, however, either because stations cannot (completely) sense the channel or because of the delay that it takes for a signal to propagate between stations. Stations recover from collisions, either by retransmission after sensing a collision (or sensing a jamming signal that alerts stations of a collision) or after timing-out while waiting for an acknowledgment. In order to prevent successive collisions, stations typically generate a random number that determines the waiting period before

retransmission. Random access protocols are simple and provide rapid response during light traffic. A new station can join the broadcasting station set at any time, and a station can stop participating without causing a loss of utilizable bandwidth. During heavy traffic, however, successive collisions cause degradation of throughput, as few frames are delivered. Access to the channel is probabilistic, so that real-time constraints cannot be guaranteed. In addition, the longer the propagation delay, the longer the period of contention. The IEEE 802.3 standard set 2500 meters (2900 with maximum drop cable length) as the maximum distance between two stations, thus limiting the contention interval. The transmission rate is increased ten-fold in Fast Ethernet, requiring a corresponding decrease in the network's diameter.

Early communication systems used random access. Since traffic was usually light, radio broadcast frequencies or telephone party lines were allotted by time (FCFS); typically users that "sensed" transmission deferred to current users. Only informal protocols were used to resolve simultaneous attempts to seize the channel.

The first computer network to employ broadcast transmission was Alohanet, a radio broadcasting system, operational at the University of Hawaii by 1971. In pure Aloha [1] and in slotted Aloha [18], stations use broadcast radio to transmit frames as soon as they are obtained from their users. The environment does not allow stations to ascertain the state of the shared channel (i.e., they cannot sense the frequency channel assigned to transmit towards the switch). Since broadcasts can collide (and interference from other terrestrial sources is not infrequent), an acknowledgment is required. If the acknowledgment is not received in a specified interval, the sending station times out and resends the frame. Contention is (possibly) resolved by requiring that stations wait a random interval following collision before resending. Note that this policy has the disadvantage of doing exactly the wrong thing when transmission failure is caused by noise, rather than collision. Fast response time is obtained during light traffic conditions (ignoring noise), but throughput is always limited. Maximum achievable channel utilization is estimated at .184 and .368 for pure Aloha and slotted Aloha respectively. Scheduling goals of fairness, priority assignments, and bounded service are not addressed. Throughput suffers drastically when the frame arrival rate exceeds 50% or 100% of channel capacity for pure Aloha and slotted Aloha respectively. Utilization is improved with C-Aloha, where the Capture property of repeaters enables the salvage of the strongest transmission of competing stations. The advantages of random access make Aloha still useful today. For example, AX.25, a packet switching protocol for ham operator networks, does not define a channel access method, but typically utilizes a variation of pure Aloha.

Carrier Sense Multiple Access (CSMA) is a random access scheme in which stations sense the state of the channel and are restricted from transmission if the channel is busy [11]. Once the channel becomes idle, stations send their frames with p-persistence, $0 < p \psi 1$, i.e., how long a station waits to attempt to seize the channel depends on how close p is to 1. In IEEE 802.3, p is equal to 1 (stations always transmit when the channel becomes idle).

If Collision Detection (CD) hardware is added to CSMA, performance is further improved, since sending stations can terminate transmission as soon as collision is detected [14]. Typically, binary exponential backoff is used following successive collisions, in which the probability of obtaining a transmission slot (time intervals are slotted after collision) is repeatedly halved. In 1973, Ethernet, using CSMA/CD, was developed at the Xerox Palo Alto Research Center. In 1980, a Digital-Intel-Xerox alliance announced a non-proprietary 10Mbps Ethernet Local Area Network (LAN) [4]. This standard became the basis for IEEE 802.3, although there are minor differences.

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is used in AppleTalk's LocalTalk network [13]. When transmission completes, a station waits an interdialog gap, typically 400 microseconds, to allow for a transmission response. If the system is still idle, and continues to be idle for a random interval, the station can transmit. If deferrals or collisions increase, the random waiting interval is correspondingly increased.

In the same period that Ethernet was developed, Mitre Corp. was working on a CATV broadcast-based system called MITRIX [14]. In contrast to Ethernet, which was originally designed for baseband coaxial cable, (single channel necessitated by digital signals) and used a distributed algorithm for access control, MITRIX relied on a central controller polling over an FDMA system that required analog signaling. Although MITRIX was ahead of its time, cable modems are becoming a viable alternative for Internet access. Unlike point-to-point DSL lines, cable users share a broadcast channel, requiring assignment of bandwidth for upstream traffic and prevention of degradation of service when traffic increases. Hybrid Fiber Coax (HFC) modems contain neither carrier sense nor collision detection hardware. Two protocols that have evolved for allocating bandwidth for upstream traffic are Aloha-based, with variations for resolving collisions. . IP-based cable modems use a binary exponential backoff algorithm for resolving contention. IEEE 802.14, a standard for ATM-centric cable modems [16], has adopted a tree-based algorithm in which the headend successively partitions the set of colliding stations. A similar algorithm was presented in 1978 [5].

4.3 DYNAMIC ALLOCATION PROTOCOLS

Data communication traffic patterns tend to be non-uniform. The allocation of an entire FDM or WDM channel, or a TDM logical channel, is wasteful of bandwidth and slows average response during bursts of traffic. Random access schemes, on the other hand, cannot guarantee the satisfaction of time constraints that are required by multimedia applications and may completely degrade when traffic increases.

Protocols have been developed to obtain time intervals for data on a demand basis, with a comparatively small amount of bandwidth sacrificed for access control. Contention-free protocols use fixed assignment schemes to reserve bandwidth for data. They reduce, but do not eliminate the delay in response time for stations, as each station must wait its turn to request bandwidth. In addition, mechanisms increase the risk of synchronization failures, since stations must synchronize their requests for broadcasting frames, in addition to their frames. Contention-based protocols, on the other hand, combine random access with contention-free mechanisms to achieve fast response time and simplicity during light traffic, with high throughput during heavy traffic loads.

4.3a CONTENTION-FREE DYNAMIC ALLOCATION PROTOCOLS

Some dynamic allocation protocols eliminate contention (assuming no occurrence of transmission errors or station malfunctioning). Instead of allocating the entire bandwidth on a fixed assignment basis, however, only a small amount is pre-allocated to reserve bandwidth for data frames on a demand basis.

The earliest contention-free dynamic allocation protocol was polling, which is still common for allocation of transmission rights by I/O controllers to terminals. The controller sends small frames called polls asking each station if it has data to send in some round robin or

priority scheme. Each station responds to the controller, even if it has no data to send. A daisy chain is an improvement of this scheme, where a station that does not have anything to transmit forwards the poll to the next station. In the early 1970s, the DoD standardized polling for the purpose of command and control busses, with MIL-STD-1553B. This standard, perhaps the most widely-used by the military for medium speed (about 1 Mbps) serial data communications, was defined to support a deterministic, command/response communications bus, not a high-speed data transfer [7] as in LANs. IEEE 802.12, also known as 100 (Base) VG-AnyLAN, is a LAN protocol that uses polling within a hierarchical structure [6]. Controllers (called repeaters), organized in a tree structure, poll all stations. There are two classes of priority traffic, but requests from the lower class are aged (their priority is raised) if they are not serviced within 300ms. If one controller goes down, most of the network can continue to function, although there may now be two distinct segments and some stations may be completely disconnected. The controller(s) forwards the frame only towards the addressed station(s), providing privacy benefits.

Token passing is a distributed form of polling, with stations passing the poll to each other in a round-robin fashion to determine transmission rights. After a token-holding station completes transmitting data, it passes the token. Lost tokens and synchronization failures can be handled by a central monitor as in IEEE 802.5 [9] or by a distributed algorithm, as in ARCnet (a 2.5 Mbps token ring, ANSI/ATA 878.1-1999 - L standard [13]) and IEEE 802.4 ([8], a token ring that is no longer supported). Frame length can be determined by a local (IEEE 802.5) or global (IEEE 802.4) timer. Transmission turns can also be controlled according to priority classes using a global timer (IEEE 802.4, Fiber Distributed Data Interface [19]). Alternatively, priorities may be determined by reservation and priority bits (IEEE 802.5).

In reservation systems, static time slots are assigned for reservations, allowing stations to reserve bandwidth on a demand basis. Reservations may be determined by toggling the value of a bit in a fixed location or by entering station information in an assigned slot. These can be TDMA slots, each allocated to a different station, as in the SPADE protocol developed for Intelsat [15]. Or they may be fields specified for reservations on each cell. Distributed Queue Dual Bus (DQDB), a reservation system introduced in the early 1990s, was modeled on QPSX, which was developed in 1985 in Australia. The media allocation protocol of DQDB (IEEE 802.6 [10]) requires stations to mark a free reservation bit in each data frame (cell) before seeking to acquire bandwidth. If a station seizes the reservation bit, counters at each station (in that direction) are updated, ensuring that no station can have more than one request pending, and maintaining a distributed queue for the allocation of bandwidth. This complex protocol, which includes multiple bits to handle priority demands, was designed for Metropolitan Area Networks (MANs).

If the number of competing stations is large, the delay in response caused by a large number of reservation slots may be unacceptable. Multiple stations can be assigned to each slot, with potential contention resolved by station identification. Leading bits of the identification identify a unique station, one by one. This method, called binary countdown, is used in DATAKIT, a fiber optics network designed by AT&T [3].

4.3b CONTENTION-BASED DYNAMIC CHANNEL ALLOCATION

Protocols may combine mechanisms to obtain the fast response time of random access schemes during light traffic together with the high efficiency of fixed assignment schemes during heavy traffic.

In some initial fixed-assignment schemes, stations contend for unused time slots. On July 10, 1962, Telstar I, a geosynchronous telecommunications satellite was launched by the Bell Telephone System. In June 1965, the first commercial satellite [4], Intelsat I, was placed in service. Because geosynchronous satellites have long propagation delays (about .27 seconds), fixed assignment schemes are common, either for reservation slots (SPADE) or for data slots (TDMA). In order to limit the waste of bandwidth with fixed assignment schemes, several protocols were proposed for satellite systems to "superimpose a dynamic time-assignment system on a fixed TDMA structure" [2]. For example, stations could use their own assigned TDMA slots to place reservations for any slot that was detected as idle. Station maintained a distributed queue by monitoring each station's reservations. If an unused slot was detected, the first station in the queue transmitted in the next turn of that slot, gaining contention-free access for subsequent rounds until the slot owner regained it. Alternatively, stations might employ variations of slotted Aloha [20] to obtain an unused slot. If the slot owner had a message to transmit, it would broadcast to its slot. The resulting collision forced the dynamically chosen station to relinquish the slot back to the assigned owner.

Random access may be used initially for reservations, in order to obtain TDM or FDM slots or channels. Very Small Aperture Terminals (VSAT) [16] for satellites has adopted RA/TDMA, in which fixed reservation slots are obtained using slotted Aloha, to request TDMA slots. In Advanced Mobile Phone System (AMPS) mobile users access a base station with random access schemes to request assignment of FDM channels. In Global System for Mobile Communications (GSM) [17], stations send reservations using a variation of slotted Aloha on a dedicated control channel. Stations are then allocated bandwidth using a combination of TDMA and FDMA mechanisms. CDMA, also called Random Access Discrete Address (RADA), allows stations to broadcast their quasi-orthogonal addresses onto the shared channel at any time. The receiver uses the address to determine its chip sequence and distinguish its data from that of other stations that are broadcasting to the channel at the same time. Note that CDMA is limited in its user population and has other characteristics of fixed assignment protocols once its signature is recognized.

Random access may be used for initial access to the channel, such that contention free mechanisms are used only following contention. IEEE 802.11 was developed for wireless systems. A collision cannot readily be detected in this environment, since a sender's transmission signal overpowers any incoming signals. Therefore the cost to correct collisions would be greater than in CSMA/CD. 802.11 consists of two "coordination functions" that determine when a station can transmit. The Distributed Coordination Function (DCF) uses a variation of CSMA, with different priority classes assigned different waiting periods for transmitting (a variation of p-persistence). High priority traffic, such as acknowledgments of data frames, polls, Request To Send frames, and frames that are part of a multi-frame message need wait only a Short Interframe Space before transmitting. A (optional) Point Coordination Function assigns a device an intermediate Interframe space to support polling. The Point Coordination Function supports real-time applications; since collisions are avoided using polling, stations' time constraints can be satisfied. All other traffic is assigned the longest Interframe Space, with stations required to delay broadcasts for different intervals following the completion of a transmission, in order to avoid collisions (CSMA/CA).   In wireless LANs, stations cannot

always sense the transmission of competing stations. For example, if stations A and C are both on either side of station B with which they are attempting communication, A and C may be outside the range of each other's reception (called the hidden station problem [20]). In addition, station D may be within range of station E's transmitter, and defer to transmission that E is sending to F, even though F is outside the collision domain of D (called the exposed station problem). Thus carrier sense on wireless media is imperfect. In addition, a sender using a cellular system does not even know if the receiver is in contact range. Therefore, IEEE 802.11 (optionally) includes two short control frames that are sent before the data, a Request To Send reservation and a Clear To Send acknowledgment. If collision occurs with the RTS frame, stations attempt to resolve contention with binary exponential backoff. If the RTS and CLS frames get through, they contain sufficient information about the sender, receiver, and length of communication to allow stations within range to avoid collision on data frames. Thus 802.11 uses a combination of initial random access allocation for data or for reservations, and can alternate to polling if traffic patterns warrant this type of control. This method can guarantee bounded response time, as does 802.3, which resolves contention with polling following 16 successive collisions.

Recently, we have seen the development of Personal Area Networks (PANs) or piconets, which connect wireless hand-held and peer-to-peer devices over short distances. Two leading technologies for PANs, Bluetooth (IEEE 802.15) and IEEE 802.11b, use variations of random access schemes for initial media access, combined with contention-free schemes when required.

5. CONCLUSION

At the present time, random access methods dominate the field of broadcast protocols in LANs and wireless networks. IEEE 802.3 has the majority of the LAN market. Although it appeared at one time that collision-free schemes such as Token Ring and ATM (a switched technology) might gain significant market share, this has not happened for a number of reasons. Certainly, Ethernet is nonproprietary, and its early development and subsequent maturity render it cheap and easy for network personnel. 802.3 has been standardized for baseband and broadband cable, twisted pair, and fiber optics and for topologies including bus, tree, and star. In addition, we feel that the access protocol itself is a major factor in its popularity. The simplicity of CSMA is partially responsible for its low cost and its ability to adjust to various modifications for different protocol requirements. During low access traffic, it provides fast access, without polls, tokens, or reservations and their resulting delays and potential synchronization errors. Its resilience ensures high availability; a malfunctioning station can typically be handled by a reset within seconds, and a synchronization or transmission error will not affect the functioning of the protocol. When lower collision rates are required, hardware such as switches and hubs limit the collision domain, as well as facilitate maintenance. Polling has been integrated into 802.11 to satisfy real-time constraints. Perhaps most important, where high throughput is required, as in multi-media applications, the simplicity of the protocol has eased the transition to 100 Megabit and Gigabit standards, which are compatible with the 10Mbps standard. Interoperability issues have supported the popularity of 802.11b, as well as the development of an Ethernet-based MAN.

Although we have restricted our multi-access protocols to communication systems in this paper, this overview is applicable to many resource systems. Different types of access control

mechanisms are frequently combined to satisfy conflicting scheduling goals for non-uniform traffic conditions.

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