IEEE 802.11
Wireless Access Method and Physical Layer Specifications

Title: A Measure of Performance: Watts per Kilobyte-Hectare

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Abstract:

Submission [1] contains the "assumption that all stations can see each other. " While this is indeed the presumption upon which cable-based LAN protocols were designed, it may be an invalid assumption for wireless LAN's. The author attempts to quantify errors introduced into performance estimates by making that assumption.

Performance judgment is often based solely on data throughput measures. This paper introduces the concept of a performance parameter with units of Watts (of transmit power) per kilobyte (of data successfully communicated) over an operating area (herein quantified in hectares because is sounds better than square meters).

The conclusion is reached that a point coordination function is necessary for efficient wireless LAN operation.

Introduction:

There is a temptation to assume that all stations can "hear" each other when doing an analysis of wireless LAN operation because this assumption simplifies the situation greatly. However, that condition hardly ever exists in the real world. If the condition is rare then the assumption should be made only if it can be shown to introduce little error into the results of the analysis. The following discussion attempts to quantify the error introduced by the assumption into the analysis of "CSMA-like" operation without a point coordination function.

Note that the author makes the following equally insupportable assumptions in this paper to simplify the analysis. It is assumed that the transmit and receive distances are equal to each other in all transceivers, and that these distances are equal for all units. No account is taken for local obstruction of the signal within the working area or for interference from other sources. Further, the paper assumes that the communications distance is equal to the carrier sense distance.

The use of Watts per kilobyte-hectare as a performance measure (smaller is better) seems logical since:

- A limiting constraint on PHY designs is the amount of transmitter power legally allowed

- The customer is buying the service of communicating bytes of information
- A major system performance factor is area of coverage

Geometric Calculation:

Figure 1 symbolizes the situation for a particular working area described by a circle of radius **r** in which wireless LAN stations may operate. The operational transmit and receive distances for these stations is also described by a circle of radius **r**. The stations are assumed to be evenly distributed over the entire area of the circle as represented by the small dots. Figure 1 highlights the locations and transmit/receive coverage of Stations A, B, C, and D for discussion purposes.

Station D, located at the exact center of the area can communicate with the three other stations; indeed, it can communicate with all other stations in the area. No other station in the area can communicate with all other stations in the area. For example, a station one unit distance to the left of Station D can not hear Station B. As expected, stations on the periphery of the area, such as Stations A and B, are not able to communicate with many other stations. However, note that Station C is near the center of the area and it cannot hear Stations A and B and lots of other stations in the lower portion of the area.

Formula [1] yields the intersecting area of two circles of radius **r** where one circle's center is **r'** from the center of the other circle.

[1] $$2\left[r^{2}\cos^{-1}\left(\frac{r'}{2r}\right) - \left(\frac{r'}{2}\right)\left(r^{2} - \left(\frac{r'}{2}\right)^{2}\right)^{1/2}\right]$$

Assuming that there is one station for each square unit of area, Formula [1] also yields the number of stations that can be heard by any station **S'** that is distance **r'** from the center of the area. Dividing this result by the total area of the circle results in the percentage of stations that can communicate with **S'**. Subtracting this percentage from 1 yields the percentage of stations that **S'** cannot communicate with.

To determine if any two particular random stations within the area can hear each other we need to pick two stations with coordinates **r', Ä'** and **r'', Ä''** and calculate the distance between them using formula [2].

[2] $$\left[(r'\sin\text{Ä}' - r''\sin\text{Ä}'')^{2} + (r'\cos\text{Ä}' - r''\cos\text{Ä}'')^{2}\right]^{1/2}$$

When the distance is less than **r** these stations can hear each other.

Simulation: Do you hear what I hear?

Formula [1] can be used in a Monte Carlo simulation of station-to-station traffic to determine the frequency of packets not reaching their destination because the intended receiving station is not within range of the sending station.

To determine the percentage of instances when **S'**, the station that wants to send, at distance **r'** from the center of the area and the intended receiving station **R'** are out of range of each other, >1000 instances of attempts to communicate were run by Monte Carlo simulation. The calculation of random distance **r'** from the center is weighted for the increasing density function of units at increasing distance from the center. A linearly increasing density function is used because of the limitations of the simulation package. Geometric Formula [1] will calculate the percentage of stations with which any station **S'** can communicate and therefore the chance of not communicating with any intended station **R'** which is uniformly distributed in the area.

The simulation (details are in Appendix) shows that in the average case the transmitting station cannot reach 41% of the working area. This can be stated in another way —the receiving station is not within range 41% of the time.

Conclusions: The situation is not as bad as it would appear. Two traffic or operational patterns reduce the occurrence of the simulated situation.

In the small ad hoc group meeting case the stations can be assumed to be within range of each other so 100% of the packets can be assumed to reach their destination.

The author believes that the majority of traffic, in other than the small ad hoc group case, is not peer-to-peer but is rather between workstation and an access point to fixed resources (servers). It is reasonable to assume that Station D of Figure 1 is the access point to those resources. Since all stations in the working area can communicate with Station D, the majority of actual traffic is between two stations that can hear each other.

The traffic that is station-to-station within the working area could reach its destination reliably if it was relayed through Station D. The relaying function is a subset of point coordination functions so Station D becomes both an access point and a point coordination function.

Collisions on the Data Highway

Formula [2] can be used to examine the particular case of "CSMA-like" traffic in the Monte Carlo simulation scenario above. In addition to data not reaching its destination due to an "out of range" condition there is a percentage of data not reaching its destination because there is a collision between transmissions when two stations could not coordinate with each other due to not being able to hear each other.

To calculate the probability of collision a Monte Carlo simulation is run for successive units of time. In each unit of time one station S' at a weighted random distance r' from the center of the area and a random angle Ä' is transmitting to station X at weighted random distance rx from the center of the area and a random angle Äx. In the same unit of time another station S" that is at a weighted random distance r" and a random angle Ä" in the area wants to transmit. If S" is farther than r from S' it cannot hear S' so S" starts transmitting. A collision is caused if station X is within distance r of station S". The author has not calculated the probability of success of S" transmission.

The simulation results show that 9.35% of the time the above scenario happens there will be a collision at the intended receiving station. This breaks down as follows. As shown earlier 41% of the time X can't hear the transmission from S' anyway so it doesn't matter if another station starts to transmit. Twenty-two percent of the time X can hear the transmission from S' and S" can't hear the transmission from S' setting up the potential for a collision at X. Finally, 9.35% of the timeX hears S', S" can't hear S', and X hears S" causing a collision.

Since the author believes that the majority of the traffic is between workstation and access point, another simulation was run in which Station D is the access point at the center of the working area and all traffic is from workstations to the access point (rx=0 and Äx=0). Since S" can't hear S' 41% of the time and since Station D can hear all workstations there are collisions 41% of the time for all data from workstations to the access point. Obviously all stations can hear when the access point is transmitting so there are zero collisions for data from the access point to workstations. If traffic patterns are symmetrical then collisions would occur for 20.5% of the simulation scenario.

Conclusions: In summary, under heavy traffic conditions using CSMA-like protocol (without a point coordination function) only 50% of the station-to-station transmissions and only 79.5% of the station-to-access-point transmissions would be successful in the simulation scenario.

This scenario points out the basic logical fault in wireless "CSMA-like" operation. The premise that a potential transmitter listens to the medium to hear operating transmitters means the distance to the operating transmitter is important for the listening action. But, if the station decides it can transmit, the important distance for collision is the distance to the receiving station, a distance totally uninvolved in the decision to transmit.

Overlap in a Channel

Next this paper examines the situation of overlap in a single channel as represented in Figure 2. Stations A and B and Access Point 1 form one basic service area. Station C and Access Point 2 form basic service area number 2. As can be seen from the drawing any transmission from Station C will act as interference to Station B (and vice versa).

Station C coverage overlaps with BSA 1 only very little so when Station C listens before talking in a "CSMA-like " protocol it hears very few of the BSA 1 stations and is therefore not likely to hear anything from BSA 1. So anytime that Station C decides to transmit it will cause a collision at Station B's receiver if it happens to coincide with Station B receiving something of interest. Again, the basic logical fault of "CSMA-like " operation in a wireless environment.

In a point coordination function protocol such as CODIAC all the synchronization and control information originates from the two access points. Since the access point coverage areas don't overlap there is no mutual interference of one BSA operation with the other. If the time that C is commanded to transmit coincides with Station B receiving something of interest there will be a collision at Station B's receiver.

Conclusions: No protocol seems to offer a method of avoiding the interference illustrated in Figure 2. The multi-channel PHY answer is to switch to another channel but eventually there will not be a clear channel to which to switch.

Overlap of Coordination Functions

There is another overlap problem illustrated in Figure 3 where the coverage areas of two point coordination functions overlap. For the WMAC protocol the TIMS signals, if being used, are being broadcast by stations labeled AP 1 and AP 2 for their respective BSA's. For the CODIAC protocol stations AP 1 and AP 2 are transmitting the synchronization of the deterministic superframe structure for their respective BSA's.

What happens to Station B when it can "hear " both coordination sources? If there is no coordination of the synchronization signaling there will be times when they collide with each other. A probability calculation would show that most of the time the short synchronization frames will not collide. If each BSA has a unique ID included in the synchronization frame then Station B can distinguish the one it wants to use. There are a variety of ways the committee might decide to approach this problem. Some of the actions that all stations hearing two point coordination functions at the same time could take are:

- Not transmit at all
- Transmit a special frame that tells the point coordination function to which they belong that the situation exists (supposedly this information would be passed on to network managers who might decide to take some action or cause a change to another channel if possible)
- Transmit a special request to their point coordination function that contains information about the timing of the "foreign " point coordination function's synchronization (supposedly this information could be used to keep the two synchronization frames clear of each other)

Conclusions: There will be mutual interference between the two BSA's with any of the protocols. More work is needed to characterize the overlap problem and create some improvements.

Access Points and Point Coordination Functions:

Traffic Patterns: The primary traffic patterns are:

- Small ad hoc groups where all stations are within an area less than the range of the media
- Station-to-station traffic over a working area equal to the range of the stations
- Populations of mobile workstations within a working area which communicate with a fixed access point to reach fixed resource(s)

Ad Hoc Group: In the small ad hoc group practically any protocol will work satisfactorily. When ad hoc group access to remote and/or fixed resources is required there is a need for an access point.

Station-to-Station: Where station-to-station communications over a working area is the dominant traffic pattern the protocol and/or system implementation must be designed to deal with the high occurrence of the destination station not hearing the transmission intended for it. Some strategies for dealing with this problem are:

- Install a point coordination function in the center of the working area to which a message can be sent for relay to the other party. All stations within the working area can communicate with the station at the center of the working area as represented by Station D in Figure 1. In the simplest case, all communications between peers is conducted through the central station so the bandwidth utilization is **1/2** of the direct station-to-station method. This is not a new invention.
- Decrease the working area radius to **r/2**. Now all units within the smaller area can communicate with each other. This results in a decrease in working area to **1/4** of that in the central station method.
- Increase the effective transmitter distance to **2r**. This is not a practical solution because it requires **4** times the transmit power, or a big reduction in data rate.

Station-to-Station Performance Measurement: Using the Watts per kilobyte-hectare method of evaluating these options for station-to-station transmission shows that:

- The station-to-station scenario simulated sometimes has an **infinite** Watts per kilobyte-hectare since no kilobytes of communication happen 41% of the time
- Installing a point coordination function to relay every station-to-station message will cause a reduction of kilobytes capacity by 1/2 so the Watts per kilobyte-hectare is **2** times ideal value
- Decreasing working area so that all traffic can get through results in **4** times the Watts per kilobyte-hectare
- Increasing transmitter power so that all traffic can get through results in **4** times the Watts per kilobyte-hectare

Station-to-Access-Point: Where station-to-access-point communications over a working area is the dominant traffic pattern the protocol and/or system implementation must be designed to deal with the high occurrence of potential interfering stations not hearing the transmission intended for the access point. Some strategies for dealing with this problem are:

- Install a point coordination function in the access point. All stations within the working area can communicate with Station D at the center of the working area in Figure 1. Give the point coordination function a means of preventing the stations from interfering with each other.
- Decrease the working area radius to **r/2**. Now all units within the smaller area can communicate with each other. This results in a decrease in working area to **1/4** of that in the central station method.
- Increase the effective transmitter distance to **2r**. This is not a practical solution because it requires **4** times the transmit power, or a big reduction in data rate.

Station-to-Access-Point Performance Measurement: Using the Watts per kilobyte-hectare method of evaluating these options for station-to-access-point transmission shows that:

- The station-to-access-point scenario simulated sometimes has an **infinite** Watts per kilobyte-hectare since no kilobytes of communication happen 41% of the time
- Installing a point coordination function to control station operation will cause a reduction of kilobytes capacity by the additional overhead bytes in the protocol so the Watts per kilobyte-hectare is **marginally less than ideal**
- Decreasing working area so that all traffic can get through results in **4** times the Watts per kilobyte-hectare
- Increasing transmitter power so that all traffic can get through results in **4** times the Watts per kilobyte-hectare

Conclusions: For station-to-station traffic using a point coordination function to relay data is the most effective method by a factor of 2. For station-to-access-point traffic the point coordination function method is about 4 times more effective than other methods.

Conclusions:

The Watts per kilobyte-hectare method of evaluating wireless may not yield exact numbers but can yield ratios. This paper has shown that reliable communications between peers evenly distributed in a working area is at least 2 times more effective in Watts per kilobyte-hectare by using a point coordination function.

All proposals for battery power conservation methods, short of simply shutting down for a period of time, utilize a coordination function [2], [3], [4]. Since power saving operation by the mobile stations is so vital this alone presents an overriding case for a coordination function.

An access point is usually required for access to fixed resources.

Having concluded that the combined point coordination function and access point architecture (except in the case of small ad hoc situations) is the preferred one in the wireless environment, a follow up paper is needed to examine whether there are any advantages to CSMA-like protocols.

References:

[1] Wim Diepstraten: "WMAC Protocol, Comparison against MAC Criteria, " IEEE P802.11-93/96.

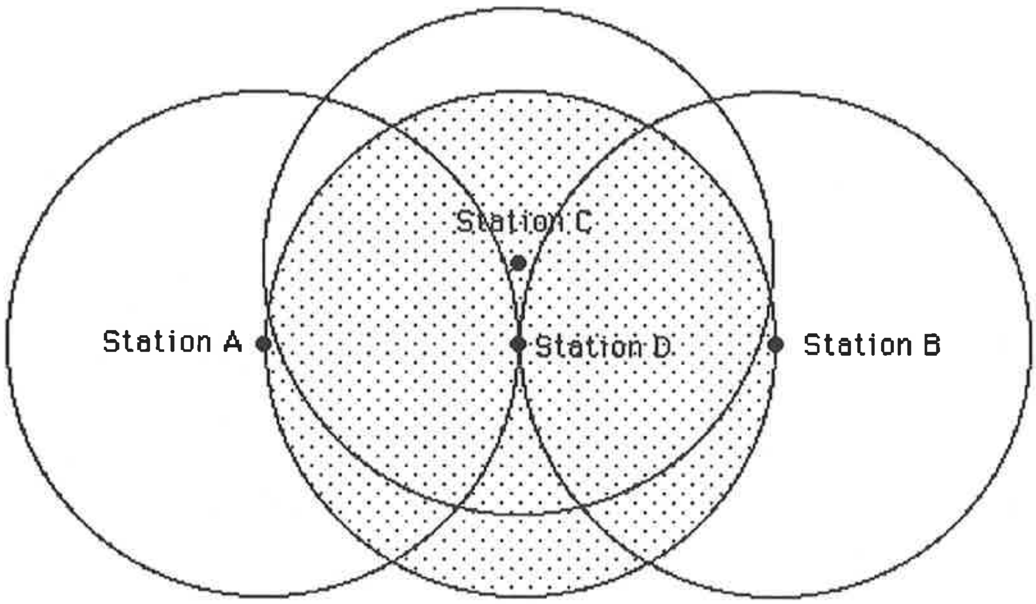
[2] Wim Diepstraten: "Power Management, The Importance of Power Management provisions in the MAC, " IEEE P802.11-93/94

[3] Wim Diepstraten, Greg Ennis: "WMAC Protocol, More Details, Synchronization and Power Management Mechanisms, " IEEE P802.11-93/95

[4] Carolyn Heide: "The CODIAC Protocol, " IEEE P802.11-93/54.

Figures:

Appendix:



Represents area of radius r in which stations are evenly distributed

● Represents the location of a station which has a transmit and receive distance of radius r

Figure 1. Geometric Analysis Representation

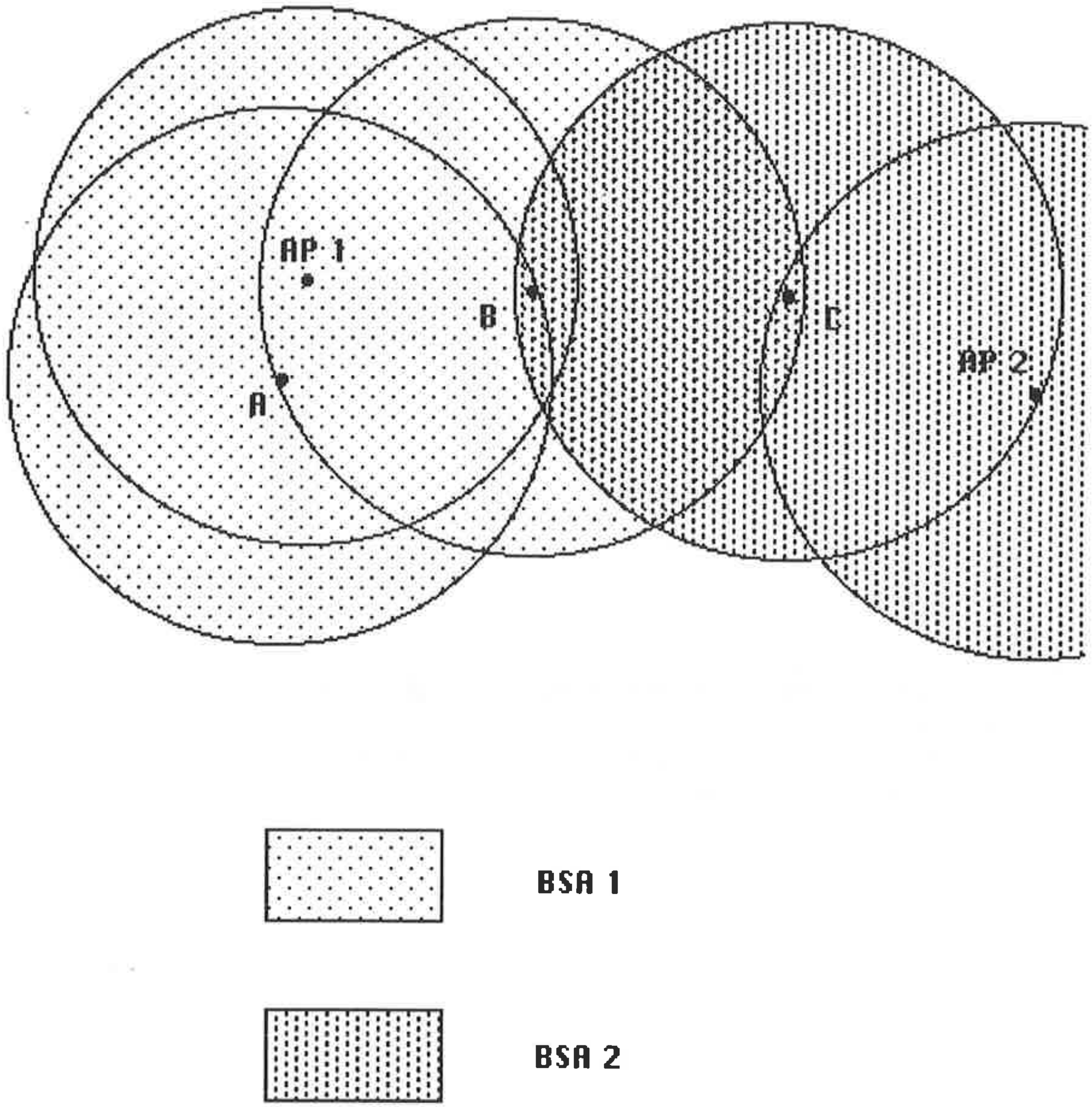


Figure 2. Two Overlapping BSA's

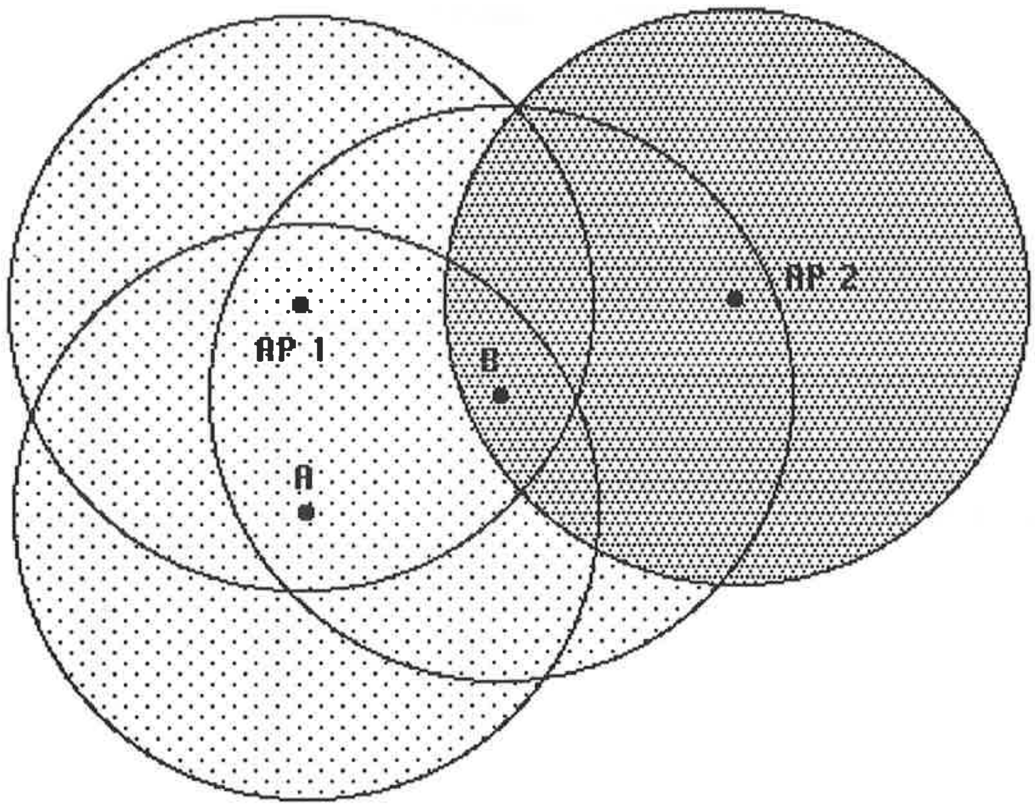


Figure 3. Overlapping Coordination Functions

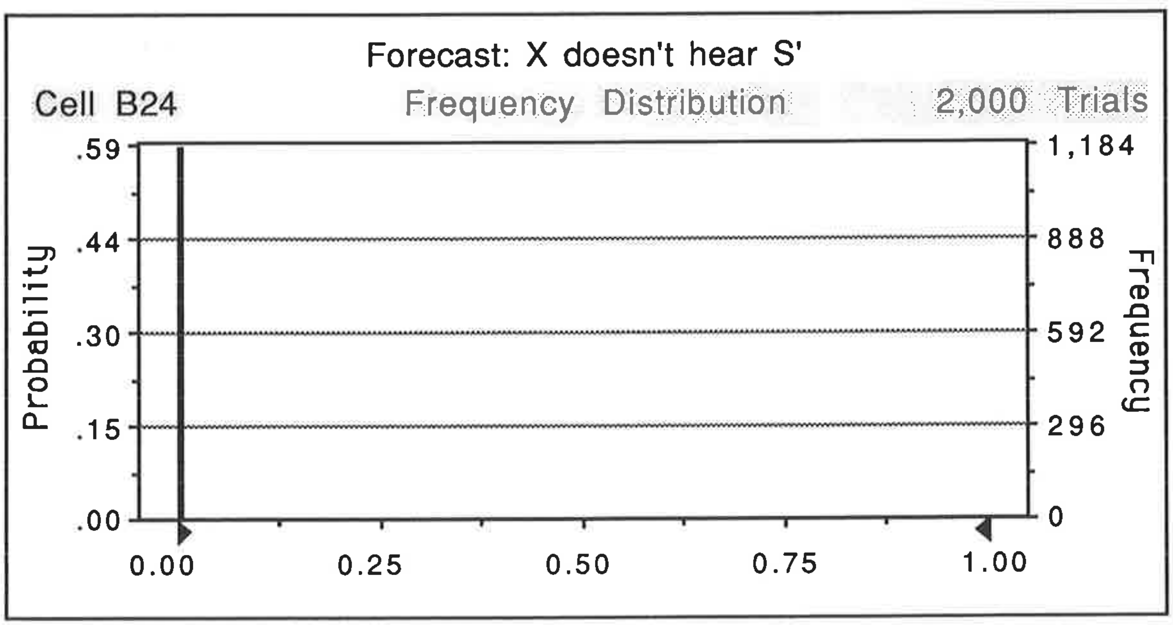
Traffic Simulation SYLK

Crystal Ball® Simulation
Started on Fri, Oct 15, 1993 at 5:25:39 PM
Stopped on Fri, Oct 15, 1993 at 5:27:32 PM

Forecast: X doesn't hear S' **Cell:** B24

Summary: Certainty Level is 100.00% based on Entire Range
Certainty Range is from -∞ to ∞
Display Range is from 0.00 to 1.00
Entire Range is from 0.00 to 1.00
After 2,000 Trials, the Std. Error of the Mean is 0.01

Statistics:	Display Range	Entire Range
Trials	2,000	2,000
Percent of Other	100.00	100.00
Mean	0.41	0.41
Median	0.00	0.00
Mode	0.00	0.00
Standard Deviation	0.49	0.49
Variance	0.24	0.24
Skewness	0.37	0.37
Kurtosis	1.14	1.14
Coeff. of Variability	120.49	120.49
Range Width	1.00	1.00
Range Minimum	0.00	0.00
Range Maximum	1.00	1.00
Mean Std. Error	0.01	0.01



Forecast: X doesn't hear S' (Cont'd) **Cell:** B24

Percentiles for Entire Range:

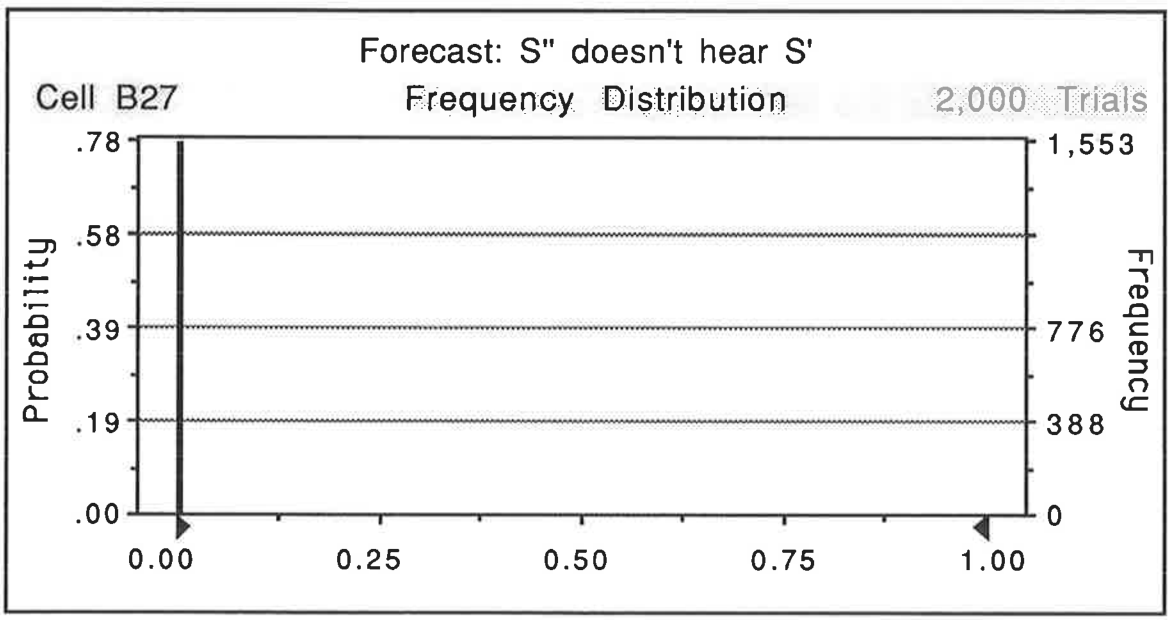
Percentile	X doesn't hear S'
0%	0.00
10%	0.00
20%	0.00
30%	0.00
40%	0.00
50%	0.00
60%	1.00
70%	1.00
80%	1.00
90%	1.00
100%	1.00

End of Forecast

Forecast: S" doesn't hear S' **Cell:** B27

Summary: Certainty Level is 100.00% based on Entire Range
Certainty Range is from -∞ to ∞
Display Range is from 0.00 to 1.00
Entire Range is from 0.00 to 1.00
After 2,000 Trials, the Std. Error of the Mean is 0.01

Statistics:	Display Range	Entire Range
Trials	2,000	2,000
Percent of Other	100.00	100.00
Mean	0.22	0.22
Median	0.00	0.00
Mode	0.00	0.00
Standard Deviation	0.42	0.42
Variance	0.17	0.17
Skewness	1.33	1.33
Kurtosis	2.76	2.76
Coeff. of Variability	186.44	186.44
Range Width	1.00	1.00
Range Minimum	0.00	0.00
Range Maximum	1.00	1.00
Mean Std. Error	0.01	0.01



Forecast: S" doesn't hear S' (Cont'd) **Cell:** B27

Percentiles for Entire Range:

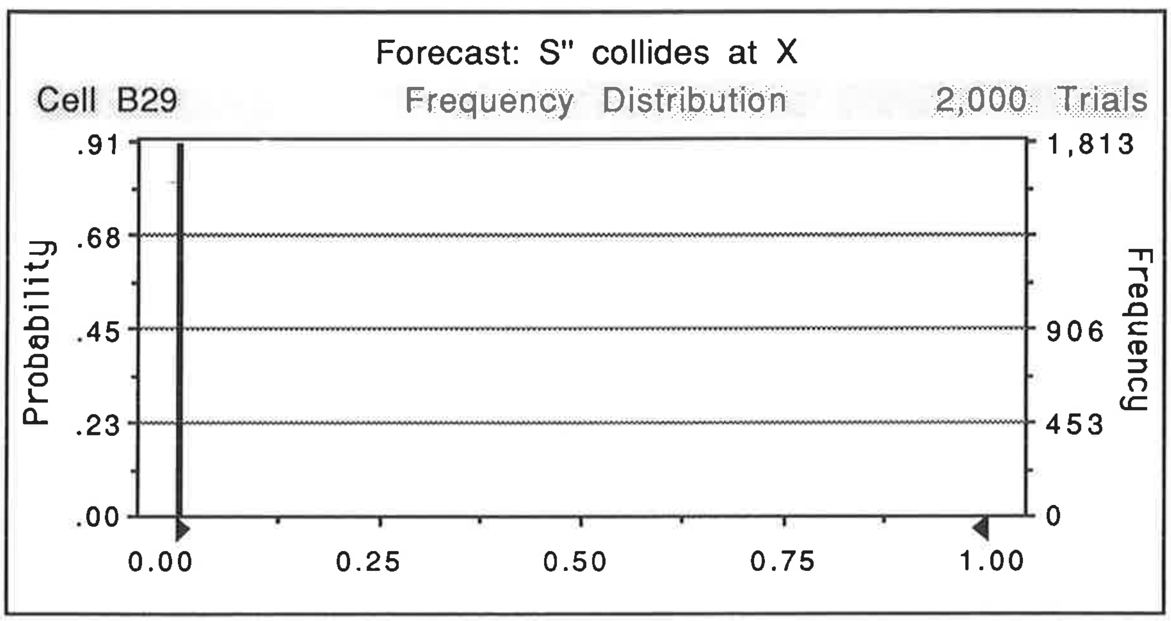
Percentile	S" doesn't hear S'
0%	0.00
10%	0.00
20%	0.00
30%	0.00
40%	0.00
50%	0.00
60%	0.00
70%	0.00
80%	1.00
90%	1.00
100%	1.00

End of Forecast

Forecast: S" collides at X **Cell:** B29

Summary: Certainty Level is 100.00% based on Entire Range
Certainty Range is from -∞ to ∞
Display Range is from 0.00 to 1.00
Entire Range is from 0.00 to 1.00
After 2,000 Trials, the Std. Error of the Mean is 0.01

Statistics:	Display Range	Entire Range
Trials	2,000	2,000
Percent of Other	100.00	100.00
Mean	0.09	0.09
Median	0.00	0.00
Mode	0.00	0.00
Standard Deviation	0.29	0.29
Variance	0.08	0.08
Skewness	2.79	2.79
Kurtosis	8.79	8.79
Coeff. of Variability	311.45	311.45
Range Width	1.00	1.00
Range Minimum	0.00	0.00
Range Maximum	1.00	1.00
Mean Std. Error	0.01	0.01



Forecast: S" collides at X (Cont'd) **Cell:** B29

Percentiles for Entire Range:

Percentile	S" collides at X
0%	0.00
10%	0.00
20%	0.00
30%	0.00
40%	0.00
50%	0.00
60%	0.00
70%	0.00
80%	0.00
90%	0.00
100%	1.00

End of Forecast

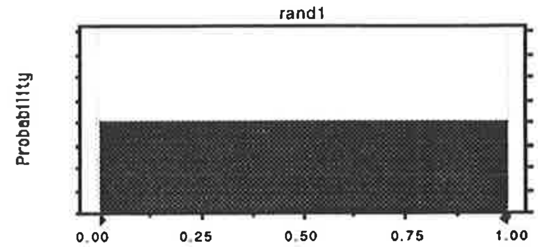
Assumptions

Assumption: rand1 **Cell:** B14

Uniform distribution with parameters:

Minimum	0.00
Maximum	1.00

Selected range is from 0.00 to 1.00
Mean value in simulation was 0.50

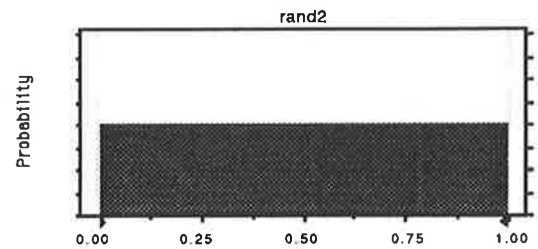


Assumption: rand2 **Cell:** B15

Uniform distribution with parameters:

Minimum	0.00
Maximum	1.00

Selected range is from 0.00 to 1.00
Mean value in simulation was 0.49

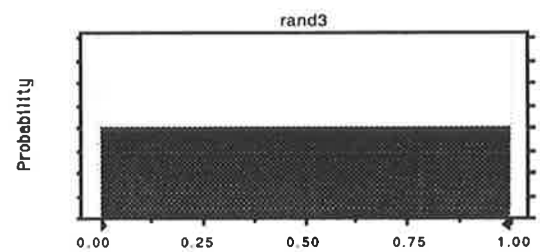


Assumption: rand3 **Cell:** B16

Uniform distribution with parameters:

Minimum	0.00
Maximum	1.00

Selected range is from 0.00 to 1.00
Mean value in simulation was 0.50

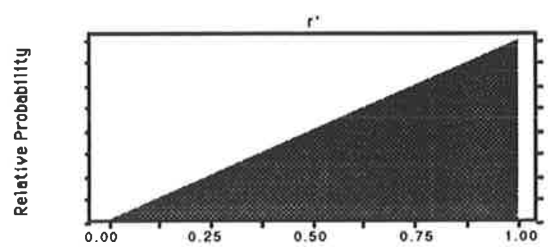


Assumption: r' **Cell:** B17

Custom distribution with parameters:

			Relative Probability
Continuous range	0.00 to	1.00	1.00
Right/Left	∞		
Total Relative Probability			1.00

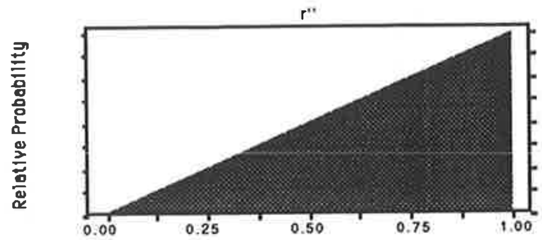
Mean value in simulation was 0.66



Assumption: r'' **Cell:** B19

			Relative Probability
Custom distribution with parameters:			
Continuous range	0.00 to	1.00	1.00
Right/Left	∞		
Total Relative Probability			1.00

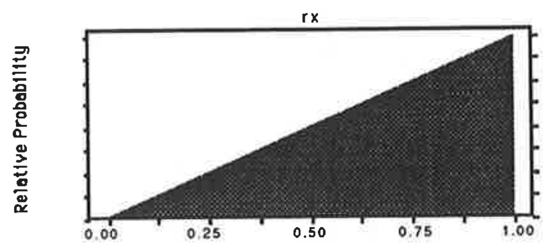
Mean value in simulation was 0.66



Assumption: rx **Cell:** B21

			Relative Probability
Custom distribution with parameters:			
Continuous range	0.00 to	1.00	1.00
Right/Left	∞		
Total Relative Probability			1.00

Mean value in simulation was 0.66



End of Assumptions

	A	B	C
10	P(r',ø',rx, øx, r",ø") of Collision		
11			
12	Variable	Value	Comment
13	r	1	Select r=1 so that r' and r" random numbers are conveniently 0 to 1
14	rand1	0	Raw random number to be used for ø'
15	rand2	0.5	Raw random number to be used for ø"
16	rand3	0	Raw random number to be used for øx
17	r'	1	Weighted random number 0 to 1
18	ø'	0	Computed random number 0 to 2π
19	r''	1	Weighted random number 0 to 1
20	ø''	3.14159265	Computed random number 0 to 2π
21	rx	0	Weighted random number 0 to 1
22	øx	0	Computed random number 0 to 2π
23	distance(S'-X)	1	SQRT((B17*SIN(B18)-B21*SIN(B22))*(B17*SIN(B18)-B21*SIN(B22))+(B17*COS(B18)-B21*COS(B22))*(B17*COS(B18)-B21*COS(B22)))
24	X doesn't hear S'	0	IF(B23>B13,1,0) where 1 means that X doesn't hear S' message and 0 means it does hear.
25	X hears S'	1	In this case it is worth simulating collision probability. (If X doesn't hear S' then the balance of simulation doesn't matter.)
26	distance(S'-S")	2	SQRT((B17*SIN(B18)-B19*SIN(B20))*(B17*SIN(B18)-B19*SIN(B20))+(B17*COS(B18)-B19*COS(B20))*(B17*COS(B18)-B19*COS(B20)))
27	S" doesn't hear S	1	IF(AND(B25=1,B26>B13),1,0) where 1 means that X hears S' and S" doesn't hear S' and proceeds to transmit causing potential collision.
28	distance(S"-X)	1	SQRT((B19*SIN(B20)-B21*SIN(B22))*(B19*SIN(B20)-B21*SIN(B22))+(B19*COS(B20)-B21*COS(B22))*(B19*COS(B20)-B21*COS(B22)))
29	S" collides at X	1	IF(AND(B27=1,B28<=B13),1,0) where 1 means S" collided with S' at station X's receiver.