THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 50, No. 6, July-August, 1971
Printed in U.S.A.

Dynamic Channel Assignment in High-Capacity Mobile Communications Systems

By D. C. COX and D. O. REUDINK

(Manuscript received January 4, 1971)

Computer simulations of high-capacity mobile radio systems using different channel assignment philosophies are described. These simulations initiate call attempts and move vehicles about randomly according to prescribed statistical distributions. Base stations and radio channels are assigned to serve mobiles and system operating statistics are accumulated. Relationships between systems parameters obtained from the simulation are presented. Performance of a dynamic channel assignment system (DYNSYS) *which has all channels available at all base stations is compared with performance of a fixed-channel assignment system* (FIXSYS) *which reserves channel subsets for use at specific base stations.*

For uniform spatial distributions of call attempts and 40-channel systems with reuse intervals of four base station radio coverage areas, the DYNSYS *outperforms the* FIXSYS *at blocking rates up to 13 percent. For example, at a 3 percent blocking rate the* DYNSYS *provides 20 percent more calls "on" in the system.*

I. INTRODUCTION

High-capacity mobile radio systems with large numbers of radio channels have been proposed to relieve the over-crowded conditions existing in mobile radio communications today. In order to make efficient use of frequency spectrum, radio coverage from base stations would be limited to small zones and channels would be reused several times within a particular urban area.[1–4] Figure 1 depicts such a channel-reuse situation along a single line of base stations. Computer control of such systems certainly would be necessary. Bounds on the behavior of simplified systems have been obtained previously[2] but the

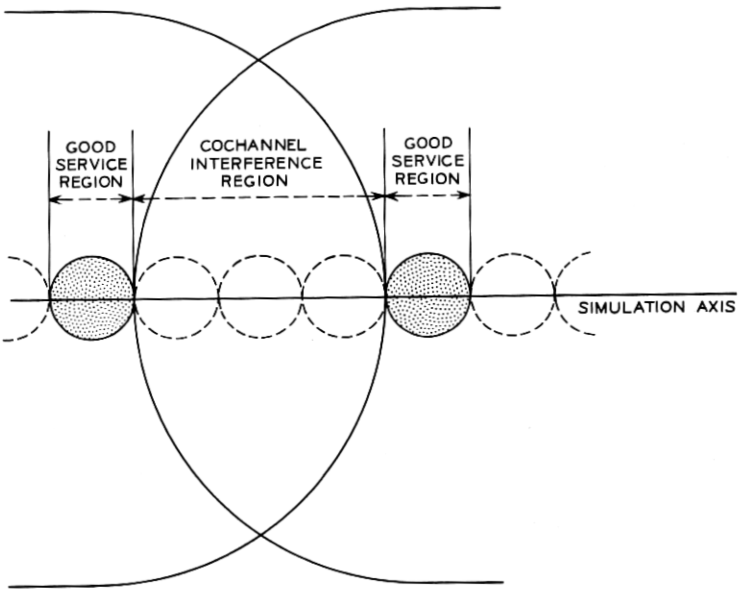


Fig. 1—Illustration of channel reuse.

problem of determining the performance of these complex systems by rigorous analytical methods does not appear tractable. Since little is known about the overall performance of dynamic channel assignment systems computer simulations were run for postulated systems whose parameters were chosen somewhat arbitrarily; however, these parameters (e.g., coverage cell size, call durations, number of channels, velocities, etc.) were selected within the wide range of values which might be experienced in an actual system. This paper presents some performance characteristics of two dynamic mobile radio systems obtained by simulation on a high-speed digital computer. This provides a means for comparing two basically different system disciplines. It should be noted that more work is required to simulate performance characteristics for actual system configurations designed to operate optimally within a specific set of conditions. No consideration has been given in this study to either the time required to develop the different system configurations or the economic factors necessary for final system design.

Channel assignment in the first system is made on a dynamic basis, that is, a channel is assigned to a requesting vehicle and its covering base station by a method which considers the channels in use at that instant at that base station and at base stations within some region surrounding the vehicle. Once a channel is assigned it will generally stay with the vehicle for the duration of the call. This may require the assignment of other base stations to that channel to cover the vehicle as it moves about.

Channel assignment in the second system is made on the basis that only a fixed subset of the channels available to the radio system are available for use at a given base station. The essential difference between these systems is illustrated in Fig. 2 where M-N indicates the channels available at each base station for a system example with 15 channels and a reuse interval of every third base station.

The first part of the paper describes a computer simulation of both systems. The second part presents performance characteristics for two different spatial-demand profiles for 40-channel systems. Throughout the paper a channel is defined as a two-way duplex radio channel.

II. OVERALL MOBILE RADIO SYSTEM OPERATION

This section describes briefly the functions which must be performed in the operation and control of a high-capacity mobile radio system and indicates which portions of the system are simulated. The major characteristics of a system are illustrated in Fig. 3. The box labeled "call initiation and vehicle motion" may be regarded as the driving function. A radio system must react to the situations created by this driver. These situations involve such parameters as the rate of occurrence and the distribution of locations of new call-attempts. Because coverage areas will be crossed as vehicles move, direction of travel and speed distributions are other influencing parameters controlled by the driver.

Since the radio path is usually not line-of-sight, propagation effects must be taken into account. The goals in this case are to assign the best base station or base stations to provide good service to the mobile and to make efficient use of the radio spectrum. The way of dealing with propagation effects can be quite varied and is closely tied to the

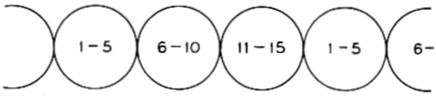


Fig. 2—Fixed-channel assignment system example.

philosophy under which base station assignments are made. One approach could be to attempt to force propagation effects to have a minimal influence by restricting the use of signal from each transmitter out to a fixed radius and then providing a margin to handle the statistical fluctuations. This would produce strong signals beyond that radius in some regions and thus would be bad from the standpoint of frequency reuse. Another extreme would be to have stored the exact coverage areas from every base station. In this case all propagation effects are known. The problem here is that of being able to store, retrieve and make intelligent decisions based on the information in a short period of time. The criterion for selection of the proper base station to serve a mobile is to provide the maximum channel reuse consistent with good service.

When a mobile requests service, a channel must be selected to serve it from the selected base station. Choosing the most distant channel currently being used may not always be the proper choice. This approach may minimize cochannel interference problems, but would be poor from the spectrum reuse point of view.

Since many of the important performance parameters of a mobile radio system cannot be obtained analytically and competing systems would be far too costly to build up in order to make the comparisons, computer simulation can be a powerful tool in providing answers for system design. At this stage the simulation to be described has simplified some of the operations illustrated in Fig. 3, but was written with the flexibility necessary for greater sophistication. Presently the model is one-dimensional. This causes some difficulty in extrapolating results to a two-dimensional mobile radio system but the results have direct application to a system laid out along an expressway or possibly to air-ground telephony. It also serves as a valid framework within which to make comparisons of different channel assignment schemes. Call initiations and vehicle movements are assumed to be random processes which will be described in detail in Section III. The propagation path between base and mobile was assumed to be such

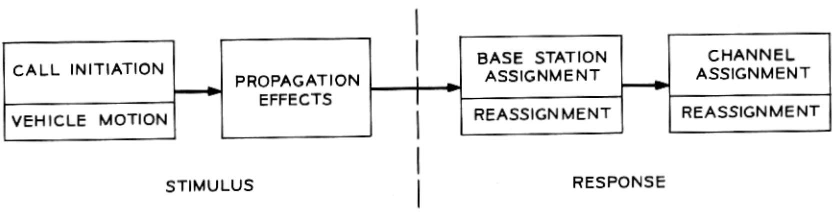


Fig. 3—Functions of a high-capacity mobile radio system.

that there is a smooth variation ($1/R^\alpha$, for example) of signal strength as the vehicle moves with respect to the base station. This assumption is of course unrealistic in many cases, but it permits the study of channel assignment methods separately from the effects of random propagation. It is assumed that there exists a distance interval over which the same frequency may not be reused. For each mobile it is further assumed that at any given instant there is only one base station which will provide a signal greater than the required thermal noise threshold and simultaneously a signal-to-cochannel interference ratio greater than some acceptable value. A discussion of the simulation of the channel assignments and of the system updating is presented in Sections IV and V.

III. CALL INITIATION AND VEHICLE MOVEMENT IN THE SIMULATIONS

Call initiation and vehicle movement in the simulation are handled in a single subroutine which is used to drive several different operating systems subroutines. The flow-chart in Fig. 4 illustrates the major sequences in this driver subroutine. For each system cycle, the subroutine steps through each subscriber in sequence and checks his activity status. Depending on events which have occurred in previous system cycles, a subscriber will be either "on" in the system or "off."

If the subscriber is not "on" in the system, the right-hand branch of the chart is followed. The first step along this branch is to generate a random number which determines whether or not a call-attempt will be made. If the result is not to make an attempt, that fact is noted and the subroutine steps to the next subscriber. If the result is to attempt a call, then another random number is generated from a uniformly distributed set to determine the subscriber's location in the one-dimensional universe of the simulation. This method of generating call-attempts produces call arrivals which are Poisson processes in time at each base station and are uniformly distributed in space. This uniform distribution in space can be weighted to produce any desired spatial distribution by using counters which reject certain attempts at some locations. A velocity is assigned to the subscriber for each call-attempt produced. This velocity is assigned from a random number set which has a prescribed density function. The simulation currently uses a truncated Gaussian velocity distribution. If the call-attempt is located near an "edge" of the one-dimensional space, it is checked against criteria used to compensate for the effects of the edges and simulate an infinite system. This compensation then

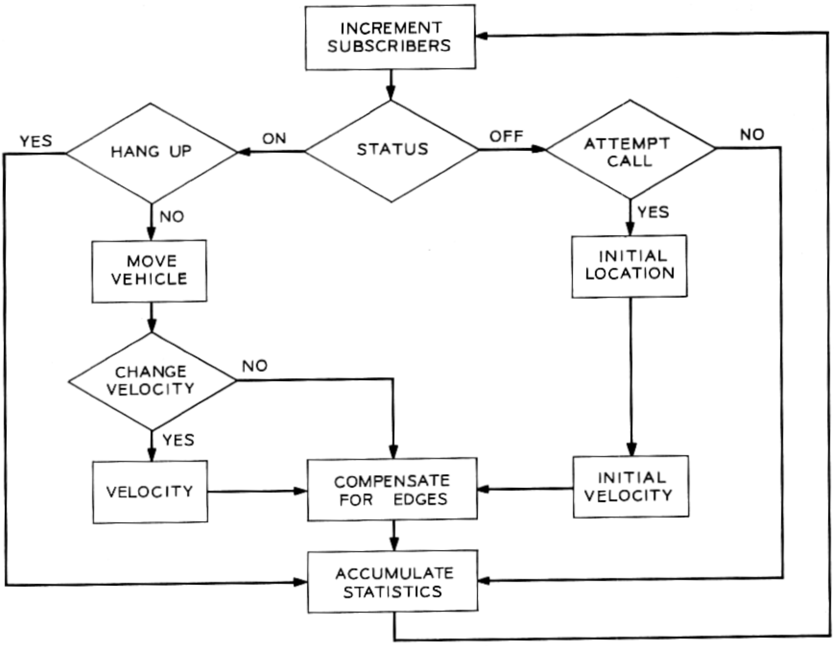


Fig. 4—Driver program.

cancels some attempts near the edges before they actually enter the system.

The left-hand branch of Fig. 4, starting at the status block, indicates the procedure followed for subscribers that are already "on" in the system. The first check is whether or not the subscriber hangs up. Call terminations are determined in a way that permits specifying the density function for call durations. The simulation currently uses a truncated Gaussian call duration distribution. Subscribers terminating calls are accounted for in the system statistics and flagged for the system operating subroutine. A subscriber who does not hang up is moved according to his predetermined velocity and the length of time between system cycles. His new location is then passed on to the system operating subroutine.

After a vehicle is moved, a random number is generated which determines if the velocity should be changed. If a velocity change is indicated, the new velocity is assigned at random following the same procedure used to determine vehicle velocities for call attempts. After vehicles are moved, those near the "edges" are again checked against an edge compensation criterion and appropriate statistical values are accumulated.

IV. A DYNAMIC CHANNEL-ASSIGNMENT OPERATING SYSTEM

In the current simulation a single operating system subroutine determines the appropriate base station to serve a call-attempt, assigns a radio channel if one is available or refuses service otherwise, and updates channel assignments as vehicles move about. The flowchart in Fig. 5 illustrates the major sequences in this operating system. For each system cycle, this subroutine steps through each subscriber who is either "on" in the system or is attempting a call and checks his activity status.

4.1 *New Call-Attempts*

New call-attempts are processed along the center branch of the flowchart. The first step in processing an attempt is to determine

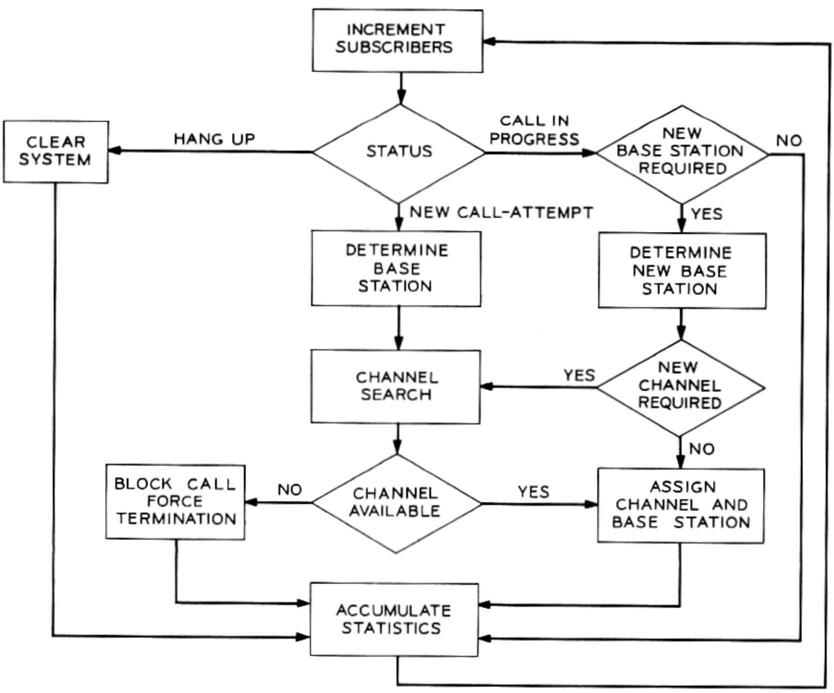


Fig. 5—System control.

which base station (or stations) should be used to serve the call. Because of the simple propagation characteristics assumed so far in the simulation, the base station nearest to the subscriber has the strongest received signal from the subscriber and will be the only one with adequate signal strength to serve. It is the station assigned to serve the call-attempt. If the base station is near an "edge" of the one-dimensional space, additional checks of the calls "on" at the base station are made. Some call-attempts near the edges of the one-dimensional space are refused service at this point if the total calls "on" at the base station to be assigned exceed some value determined by the edge compensation criterion.

The next step in processing a new call-attempt is to search for a radio channel which satisfies some channel assignment criteria. The simulation will permit many different assignment criteria to be investigated. Because of the simple propagation model assumed at this time, the current channel assignment criterion assumes that the base stations separated by greater than a certain reuse interval will not interfere with each other when they use the same radio channel (i.e., there will be no cochannel interference). The current dynamic channel assignment criterion assumes that all radio channels are available at all base stations. It also assumes no limit on available radio equipment at the base stations. This last assumption is somewhat unrealistic but it will permit the determination of upper bounds on actual radio equipment requirements. These equipment limits will then be included in later simulations. Channel search is done channel by channel starting with Channel 1. If the channel being checked is in use at the base station to be assigned, then that channel is rejected and the next channel is checked. If a channel is not in use at that base station, a check is made base station by base station on both sides of that base station. If the channel is in use at a base station closer than a reuse interval away from the base station to be assigned, the channel is rejected and the next channel is checked starting again at the beginning of the channel check procedure. If the channel is not in use at any base station less than a reuse interval from the base station to be assigned, then further checks on that channel are made and it is compared with other channels, if any, which also have met this reuse interval criterion. If, at any time during the channel searching, a channel is found which is not in use at any other base station in the system, that channel is flagged for assignment and the channel search is terminated. Otherwise, channels which meet the reuse criteria are intercompared to find the "most desirable one." The most desirable one will depend on the system operating parameter which is to be minimized, but the optimum choice has not been determined yet. For this simulation, the channel flagged for assignment is the one whose next "in use" base station is closer to the base station to be assigned than any of the other channels satisfying the reuse criterion but is at least a reuse interval plus an integer number, J, of base stations away from the base station to be assigned. The use of $J = 0$ packs assignments as close as possible on one side of the base station to be assigned but increases forced terminations of calls when boundaries are crossed. The use of $J = 1$ relieves the forced terminations slightly but results in a slightly greater separation between base stations using the same channel. In any case, if the only channel satisfying the reuse criterion is "on" at a base station exactly one reuse interval from the base station to be assigned, that channel is still flagged for assignment. This channel search strategy never allows a channel to be assigned at base stations less then a reuse interval apart, but attempts to pack channel assignments close together for efficient channel usage.

If, after checking all radio channels in the system, no available channel is found, the call-attempt is refused service (the call is blocked) as indicated on Fig. 5. Blocked call-attempts are completely removed from the system and no other attempt to serve them is made. On the other hand, if an available channel is found, it is assigned to the vehicle and the base station to be assigned and the call setup is complete. Statistics are accumulated and the next subscriber checked.

4.2 *Calls in Progress*

The processing of calls in progress can be followed by returning to the status check block at the top of Fig. 5 and following the right-hand branch. The first step along this branch checks the suitability of the current base station assignment. This is done by checking to see if the vehicle has moved (during its last pass through the driving subroutine) closer to some other base station than the one currently serving it (and thus has a stronger signal at the other base station). If it has not moved into such a situation, then its current base station and channel assignment are acceptable and no further action is taken except to account for the call in the system statistics. If, however, the vehicle has moved closer to another base station, that "now closer" station must be used to serve the call. As indicated on the flowchart, the assigned channel is then checked at the new base station to be used and at all base stations within a reuse interval of the new one. If the channel passes this check, that is, is not in use at those stations, the new base station and old channel are assigned to serve the call and the old base station is cleared of the call. If the old channel is in use within a reuse interval of the new base station, then a whole new channel search is initiated identical to the one used for new call-attempts. In the case of a call in progress, the only difference is that, if a substitute channel is not available, the call is forced to terminate instead of being refused. Only one attempt is made to switch channels for such a call in progress. In either case, the old base station is cleared of the call, statistics are accumulated, and the subroutine steps to the next subscriber.

4.3 *Call Terminations*

The only actions required to process call terminations are to clear the channel at the assigned base station and accumulate the appropriate statistics. These actions are indicated on the left-hand branch of Fig. 5.

The dynamic channel-assignment operating system used in the simulation and just described follows a simple, straight-forward operating procedure. No doubt, more efficient channel usage could be achieved if the system were continuously checked call by call and channels changed on calls in progress to more optimally pack the calls in the system and free more channels for new calls. Similarly, more efficient initial channel assignments could be achieved if attempts were made to change channels of calls in progress to try to free a channel for serving a call attempt which would now be blocked. Fewer new calls would be blocked if new callers were given several attempts over a short time period to obtain a channel rather than the one attempt allowed in the current simulation.

V. A FIXED-CHANNEL ASSIGNMENT OPERATING SYSTEM

A single subroutine simulates the fixed-channel assignment operating system. This subroutine, which is similar to the dynamic channel assignment subroutine, determines the appropriate base station to serve a call attempt, assigns a radio channel or blocks the attempt depending on the availability of a radio channel, and updates channel assignment as vehicles move about. Fig. 5 also illustrates the major sequences in this operating system but some of the block functions are different for this system. Again, for each system cycle, the subroutine steps through each subscriber and takes appropriate action.

5.1 *New Call-Attempts*

Processing of new call-attempts for the fixed-channel system is identical to that for the dynamic system down to the channel search procedure. The base station assigned to serve a call-attempt is the one nearest to the subscriber as discussed for the dynamic system.

In the fixed-channel system, a subset of the radio channels available to the system is permanently reserved for each base station. The subsets are reused at base stations separated by the reuse interval described previously. The number of channel subsets is the same as the number of base stations in a reuse interval, I. Every Ith base station uses the same channel set. (See Fig. 2.) The number of channels, C_s, in a subset is

$$C_s = C_t/I$$

where C_t is the total number of channels available to the whole system. Thus, each base station has C_s channels reserved for its exclusive use. Channel search, then, only involves searching through the C_s channels of the subset reserved for the base station to be assigned. If a channel from this subset is not in use, then it is assigned to serve the call. If no channel from this subset is available, the call attempt is refused service (the call is blocked).

5.2 *Calls in Progress and Call Terminations*

Processing of these calls also proceeds as in the dynamic system. A check is made to see if the vehicle has moved so that a different base station is required to provide service. If a different base station is not required, no system action is necessary. If, however, a different base station is now required, that base station is determined and for this fixed-channel system the only recourse is another channel search. The channel assigned at the previous base station is not available at adjacent stations so the alternative, available to the dynamic system, of continuing its use is not possible. This alternative, indicated on Fig. 5, is thus not applicable to the fixed system. The channel search at the new base station to be assigned is identical to the one described for new call-attempts. In this case, if no vacant channel is found, the call is terminated.

Subscribers who hang up are cleared from the system and statistics are accumulated as in the dynamic system.

VI. THE DRIVING PARAMETERS

The operating systems were tested for a 24-base-station 40-radio-channel network where the base station separation was assumed to be 2 miles; the minimum reuse spacing was 8 miles. This simulation assumed 1000 subscribers and operated with a 10-second cycle time, that is, within 10 seconds (in simulated time) the status of each subscriber was examined. In a true system only subscribers making or attempting calls are of interest. For simulation purposes, however, it was found more convenient to gather statistics and create demand by cycling through all subscribers. Statistics were taken from only the central 14 base stations to avoid any effects from the edges of the finite system.

The spatial location of call-attempts will vary with traffic intensity. To provide a reference system, Section 7.1 considers a uniform spatial distribution of call-attempts. In Section 7.2, an example of a non-uniform call-attempt distribution is simulated.

Call-attempts occur at random points in time (i.e., call-attempts are a Poisson process), therefore, the time difference between call-attempts should have an exponential density function with its mean equal to its variance. A histogram of the time differences for a typical data run is plotted in Fig. 6 along with a theoretical exponential curve.

The distribution of the duration of mobile telephone calls for a high-capacity system is unknown. There is, however, some minimum length of time which a mobile caller will hold a channel. For example, even a call where no one answers will create a demand on the mobile radio system of perhaps 30 seconds. The distribution of call durations for this simulation was assumed to be a truncated Gaussian with a minimum call of 30 seconds and a maximum call of 10 minutes. The mode call time was chosen to be 1-1/2 minutes with a standard deviation of 1 minute. The mean for this assumed distribution is 103.5 seconds. Figure 7 shows both a theoretical curve of the density function and a histogram of call lengths taken from a 1000-cycle data run.

The distribution of vehicle velocity was also chosen to be a truncated Gaussian. In this example, the maximum speed was 60 miles per hour; the distribution had a zero mean and a variance of 30 miles per hour. A theoretical velocity distribution and a histogram from the simulation are plotted in Fig. 8.

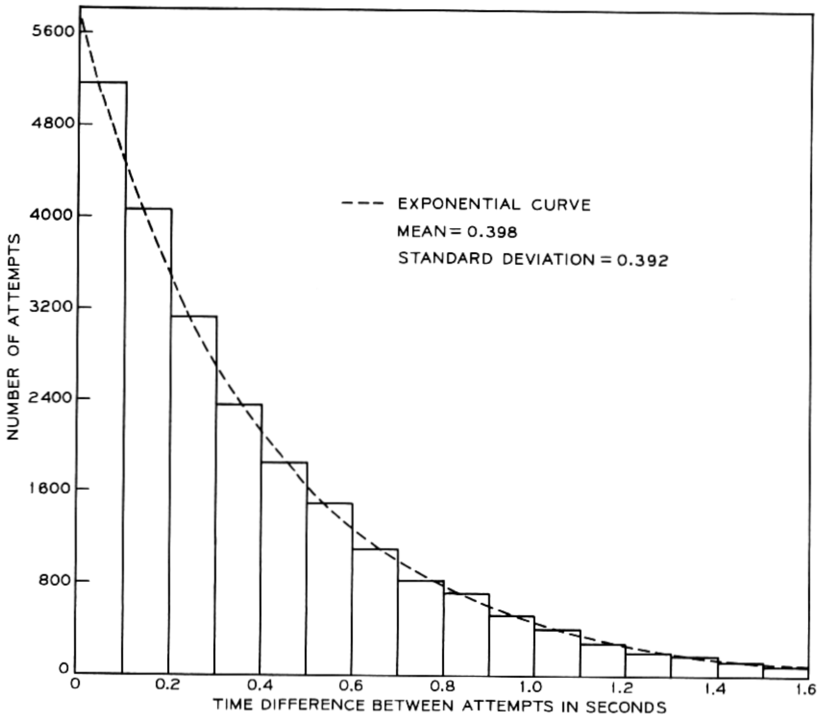


Fig. 6—Time difference between call-attempts histogram.

VII. EXAMPLES OF SYSTEM PERFORMANCE

7.1 *Uniform Call-Attempts*

The performance of a mobile radio system is measured knowing the interrelations between such parameters as the call-attempt rate, percent of call-attempts blocked, number of calls being handled, number of vehicles crossing cell boundaries, and number of calls being forced to terminate.

The location of call-attempts for this part of the simulation was chosen to be a flat distribution in space with appropriate edge tapering. Figure 9 shows the number of call-attempts at each base station for two typical data runs. Since it was desirable to take averages over this ensemble of 14 base stations the number of system cycles was

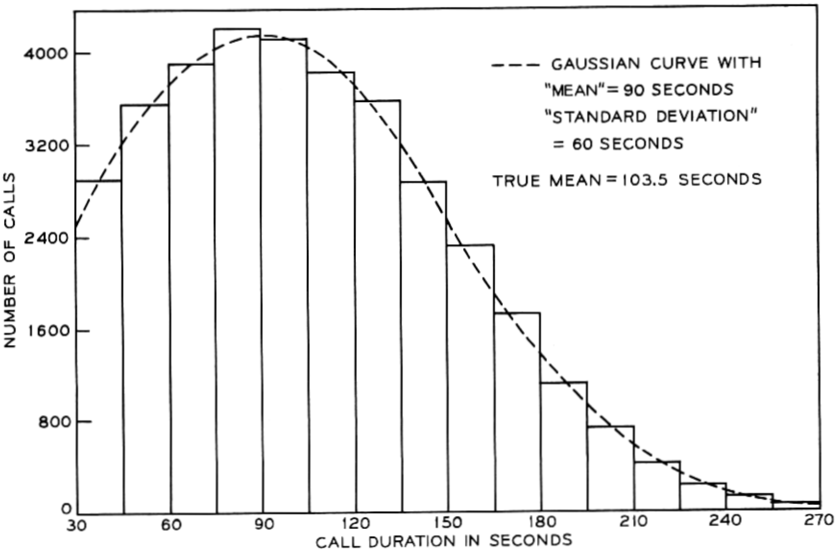


Fig. 7—Call duration histogram.

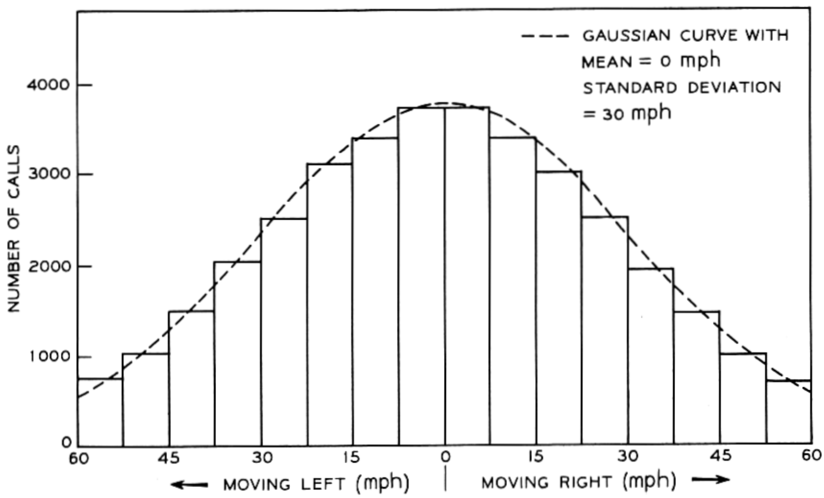


Fig. 8—Velocity histogram.

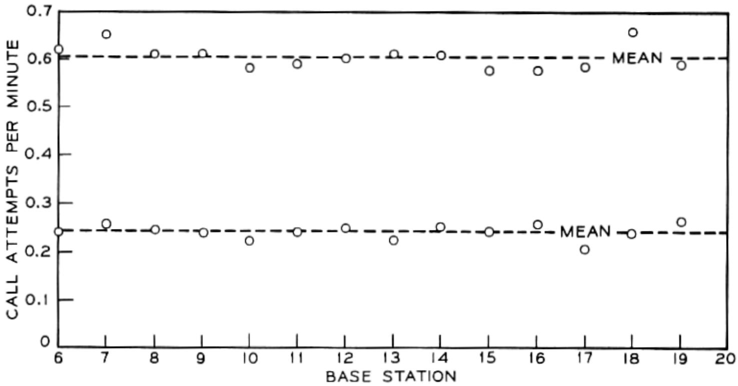


Fig. 9—Average call-attempt rate at 14 base stations for two attempt rates.

increased until the deviation from the mean number of call-attempts by an individual base station was small.

As an aid in understanding the details of the system operation, a special program was written to view at regular instants of time the status of the mobile radio system. Specifically, a computer printout was generated which indicates the locations where radio channels are being used and prints a symbol unique to that channel. The appropriate symbol for each of the 40 two-way channels is shown in Table I. In addition, two other special symbols are used. The $ is printed if, during the time interval under consideration (usually taken to be 10 seconds), a request for service was initiated but no channel was available and service was refused. The $ is printed at the location where the call was attempted. An * is printed when a vehicle crosses a cell boundary and the user is forced to terminate his call prematurely because a channel is no longer available for him.

Figure 10 illustrates the dynamic channel assignment system, DYNSYS, activity for 500 seconds for base stations 11 through 16. In the example, about 10 percent of the call-attempts are being blocked. The circled track 1 shows a typical call within the coverage area of base station 13, where the caller is assigned channel 39, designated by an open parenthesis. After 80 seconds a change in velocity occurred and the call terminated after 140 seconds. Recalling 2-mile base station spacing and 10-second time intervals, the velocity can be roughly calculated from the figure. In this example, the initial velocity was about 45 miles per hour and the final velocity was about 30 miles per hour in the opposite direction. Track 2 in this same figure shows a

TABLE I—CHANNEL IDENTIFICATION

Channel Number	Symbol
1	A
2	B
3	C
4	D
5	E
6	F
7	G
8	H
9	I
10	J
11	K
12	L
13	M
14	N
15	O
16	P
17	Q
18	R
19	S
20	T
21	U
22	V
23	W
24	X
25	Y
26	Z
27	1
28	2
29	3
30	4
31	5
32	6
33	7
34	8
35	9
36	0
37	+
38	−
39	(
40	)

vehicle with channel C crossing a boundary and maintaining the same channel. That is, the channel assigned to the call "floats" with the vehicle. When the system activity is quite high, not all callers crossing boundaries can keep the same channel. Track **3** shows a vehicle, originally assigned channel G, reassigned to channel S as it crosses the boundary between base stations 11 and 12. Note, the channel change was required because channel G was in use (circle **3′**) at base station 15 which is less than a reuse interval from base station 12.

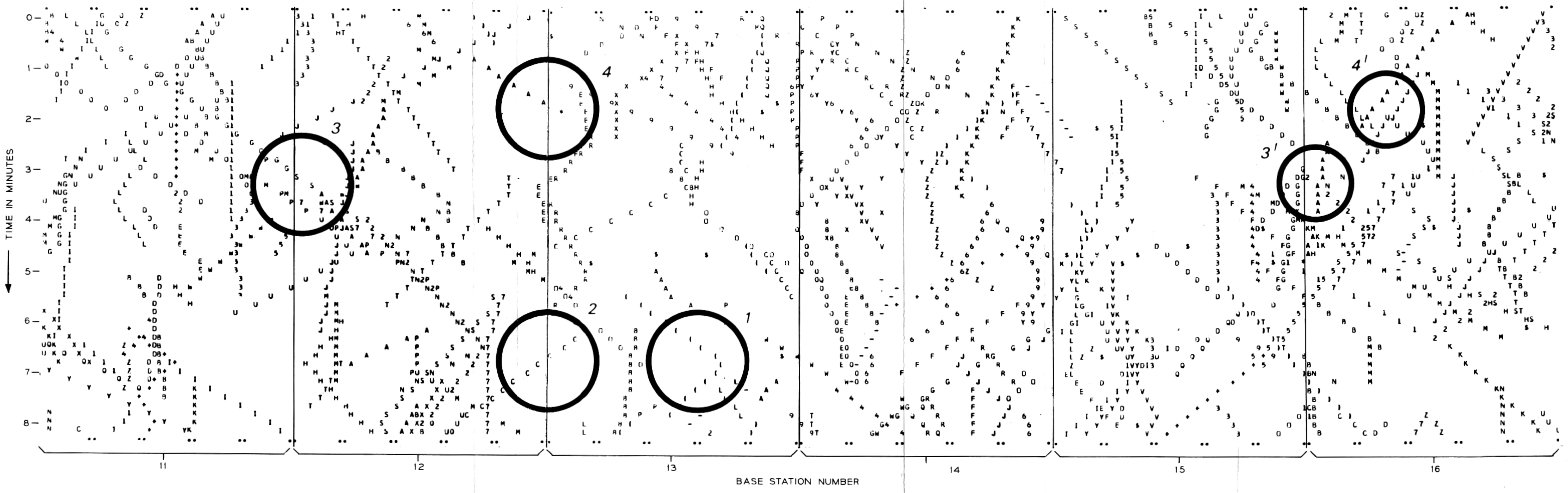


Fig. 10—Examples of dynamic channel assignment system operations.

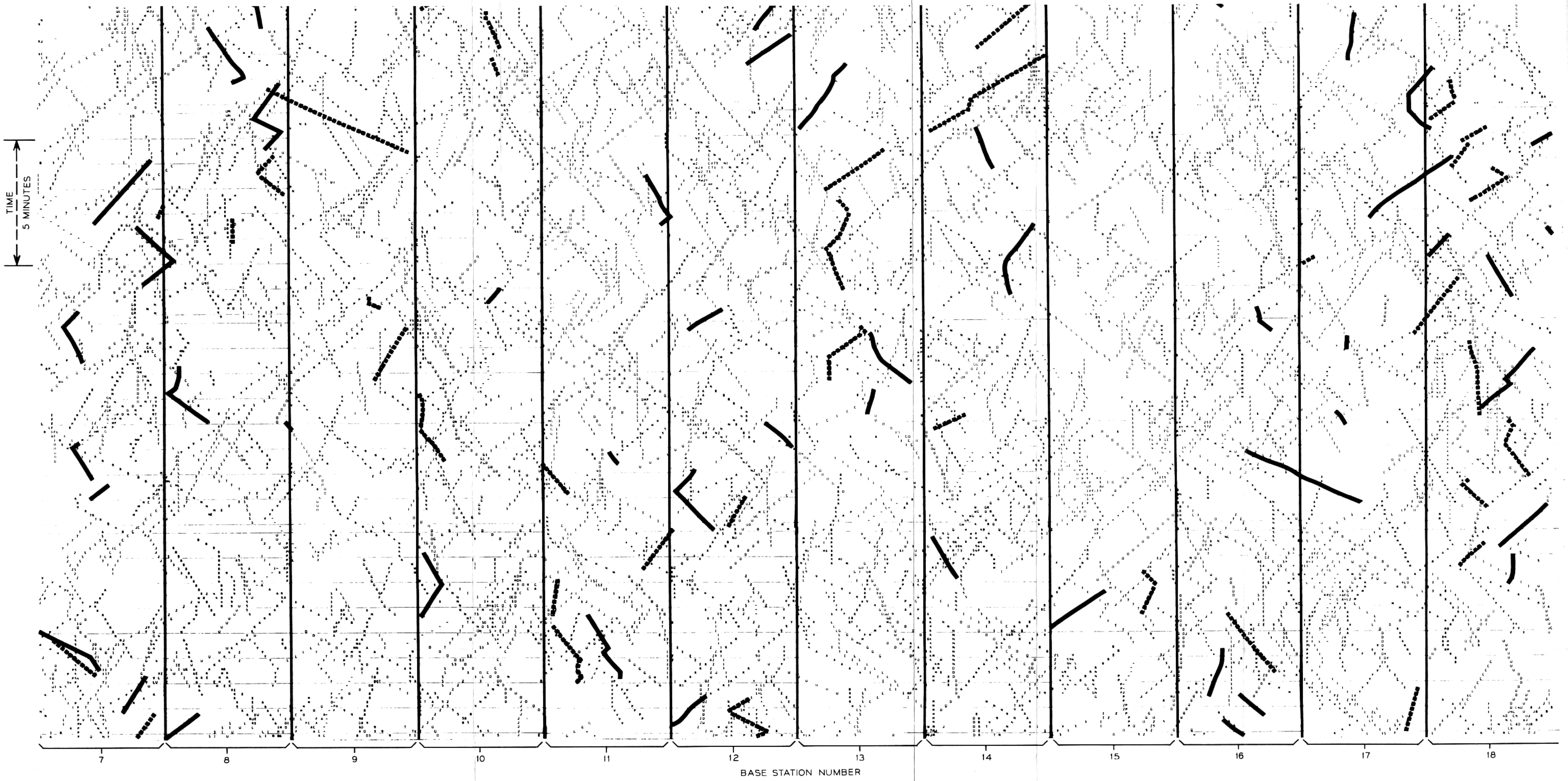


Fig. 11—Examples of channel reuse with dynamic channel assignment.

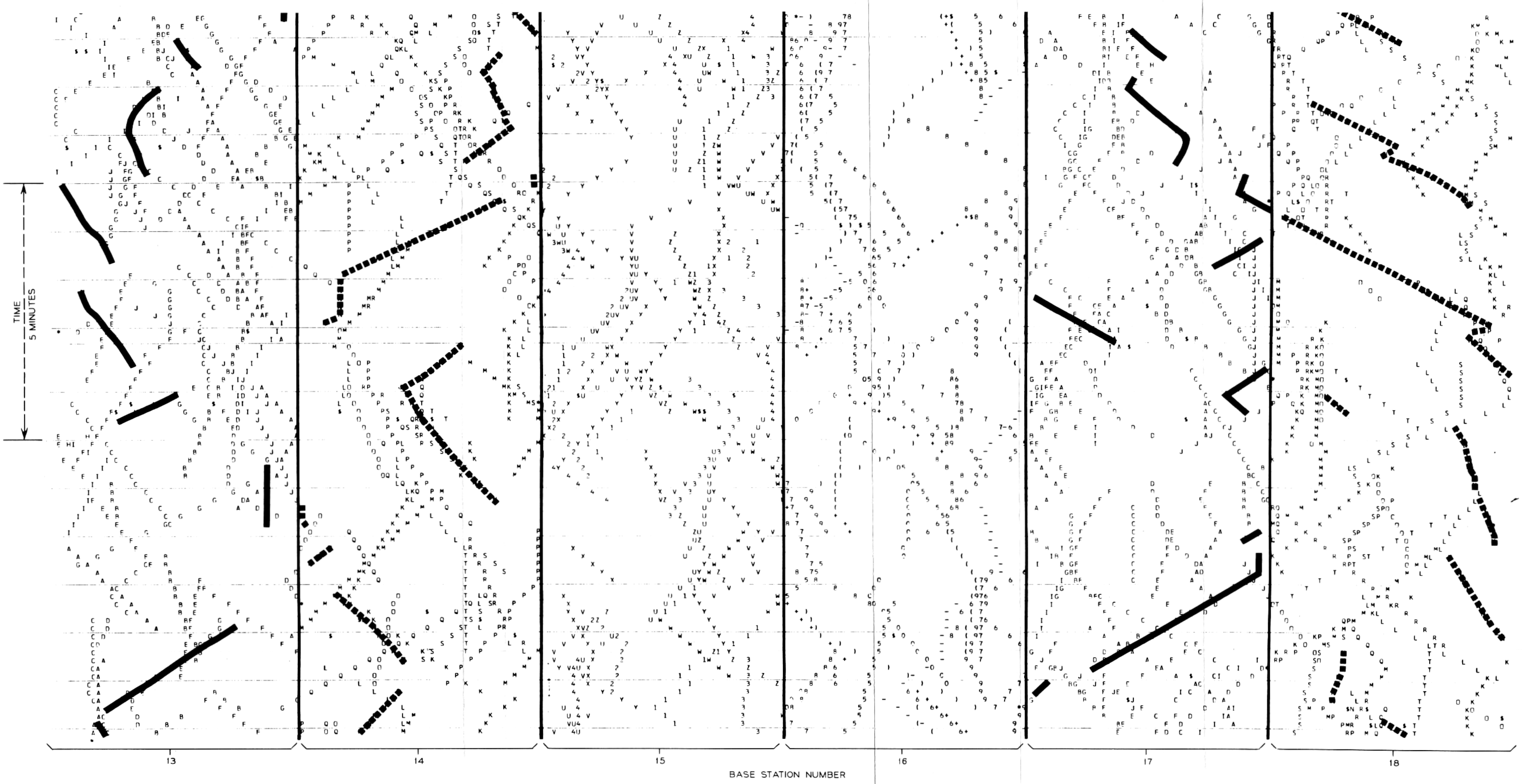


Fig. 12—Examples of channel reuse with fixed-channel assignment.

Track 4 shows a forced termination (of channel A) occurring at the boundary between base stations 12 and 13 because the channel is in use at base station 16 (circle 4′), and no other channels are available.

In the DYNSYS, any channel is available at any base station. In the fixed-channel assignment system, FIXSYS, with a reuse interval of 4, the 40 available channels were apportioned as shown in Table II. In the FIXSYS, vehicles are not allowed to keep frequencies when crossing boundaries. Therefore, a track corresponding to track 2 in Fig. 10 is not possible.

Channel reuse for the two types of systems is illustrated in Figs. 11 and 12. In the DYNSYS, calls are served on a first come first serve basis regardless of location. This system must hunt for an available channel which is not being used within a reuse interval on either side of the new caller. The highlighted tracks of Fig. 11 illustrate system usage of channels X and H during a time period of $\frac{1}{2}$ hour. The FIXSYS usage of channels H and N is illustrated in Fig. 12.

As the systems were running, data were taken on operating parameters such as the number of call-attempts, hang-ups, boundary crossings, etc., which occurred. These performance statistics were accumulated over runs of 1000 system cycles. Blocking is expressed as the ratio of call-attempts not finding a channel to the total call-attempts for a given time period. Forced terminations, which occur when a vehicle crosses a radio coverage boundary and cannot find an available channel, are expressed as the ratio of calls forced off to calls served for a given time period. Calls-keeping-channel are expressed as the ratio of calls keeping the same channel when crossing a coverage boundary to the total number of boundary crossings for a given time period. This parameter indicates the degree to which channel coverage "floats" with vehicles.

Figures 13 and 14 characterize the number of calls "on," blocking, forced terminations, and calls retaining their channel as a function

TABLE II—CHANNEL ALLOCATION FOR FIXED-CHANNEL ASSIGNMENT SYSTEM

Base Station	Channels Available
1, 5, 9, 13, 17, 21	1–10
2, 6, 10, 14, 18, 22	11–20
3, 7, 11, 15, 19, 23,	21–30
4, 8, 12, 16, 20, 24	31–40

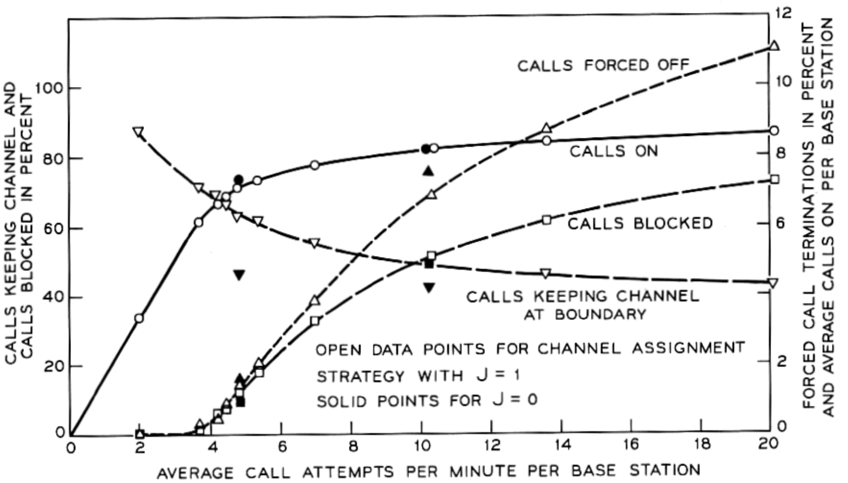


Fig. 13—Performance of a dynamic channel assignment system (flat loading).

of the call-attempt rate for the DYNSYS and FIXSYS. The values are averages per base station and the spatial call-attempt distribution is flat over all base stations.

The channel assignment philosophy currently used in DYNSYS selects as first choice a channel being used five base stations (a reuse interval plus one base station) on one side or the other of the new attempt location. In Fig. 13 the solid points are for two attempt rates where the first choice for channel assignment is a channel which is being used only four base station intervals (one reuse interval) away. As expected, the calls "on" were increased, the blockage was lowered slightly, forced terminations increased, and fewer vehicles kept the same channel after crossing a boundary.

The calls-keeping-channel curve shows that at low loading most vehicles are able to maintain their channels as cell boundaries are crossed while at very high loading, channel usage is packed more nearly at reuse intervals apart and fewer vehicles can maintain their originally assigned channel. Even at high loading, however, about half of the vehicles keep their channels as boundaries are crossed. Note, this parameter is the one most affected by the different assignment philosophies (preferred 4- or 5-station separation).

Figure 14 presents similar performance curves for the FIXSYS. Since channels must always be switched at boundary crossings the number of forced terminations is increased over the DYNSYS. When no motion is allowed and call durations are assumed to be exponentially distributed, it is possible to calculate (given the average call duration) from trunking formulas a theoretical expression for the blocking probability versus the number of calls "on" at a base station. The FIXSYS simulation, which allows motion and assumes truncated Gaussian call time distributions, agrees almost exactly with the trunking formula curves (Calls On and Calls Blocked) in Fig. 14 and Fig. 15 (dashed curve). Under the current operating conditions, motion and call time distributions have negligible effect on these two parameters.

The DYNSYS performance is compared to the FIXSYS performance in Fig. 15. In the low blocking region (below 10 percent) which is where a radio system should normally operate, the DYNSYS handles more calls than the FIXSYS. It provides about one extra call per base station (20 percent increase) at 3 percent blocking. At high blocking rates, the FIXSYS operates more efficiently; the reason is that this system can achieve a maximum number of calls "on" when there is always a call waiting at each base station. The DYNSYS could, of course, be programmed to switch over to this mode of operation as the system saturates.

As shown in Fig. 9, call-attempts were chosen to be a flat distribution in space. The corresponding reaction to the call-attempts is the

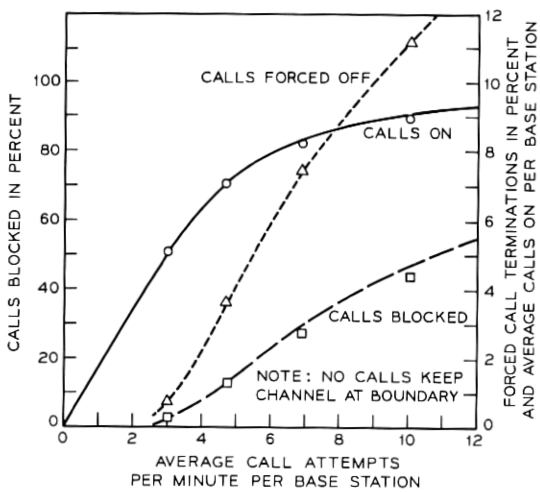


Fig. 14—Performance of a fixed-channel assignment system (flat loading).

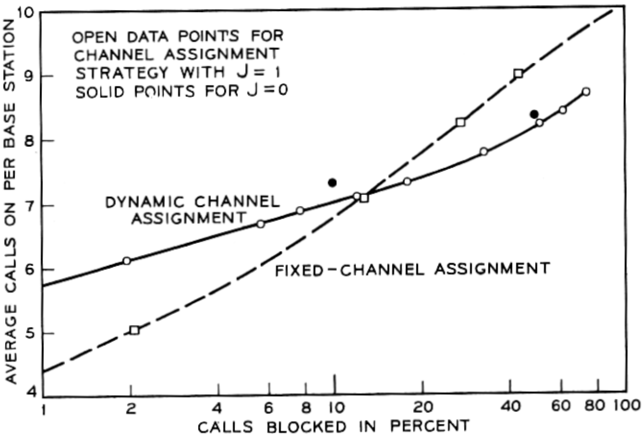


Fig. 15—Channel usage (flat loading).

average-calls-on distribution which is plotted in Fig. 16 as a function of base station for two demand rates for the DYNSYS.

The DYNSYS simulation allowed for the possibility that all channels could be used simultaneously at any base station. A histogram of the actual number of calls "on" for two different attempt rates is shown in Fig. 17a and b. It is immediately obvious that for a flat spatial distribution of call-attempts, halving the number of radio transmitters would not affect the system performance, since the number of channels

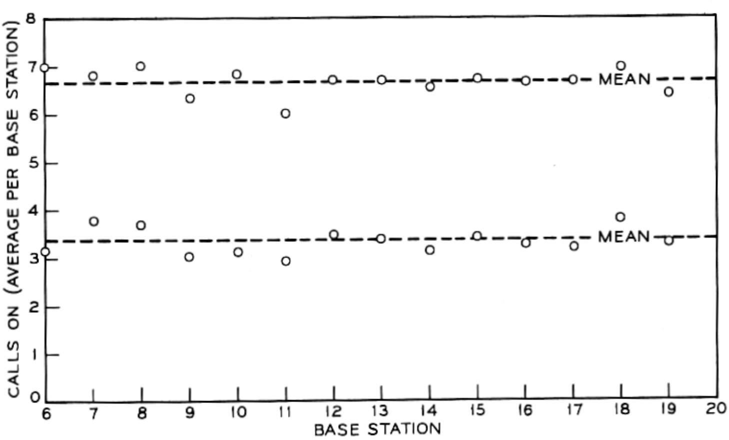


Fig. 16—Average number of calls "on" for two attempt rates.

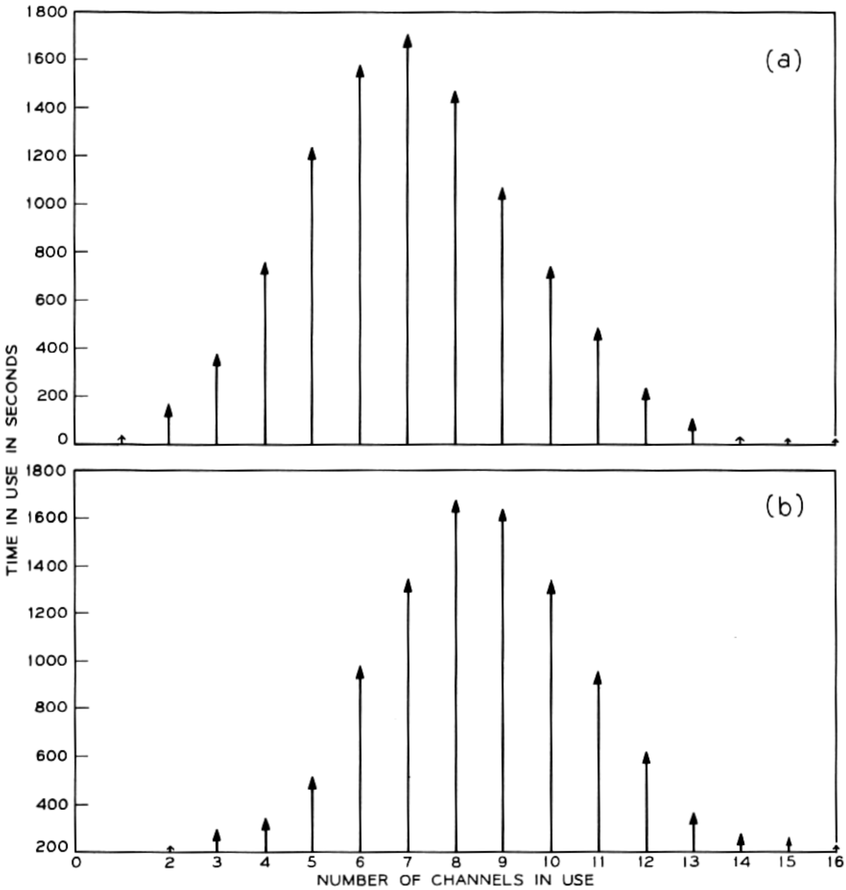


Fig. 17a—Histogram of channel usage per base station for dynamic channel assignment system with a calls-on average of 7.1.

Fig. 17b—Histogram of channel usage per base station for dynamic channel assignment system with a calls-on average of 8.66.

used at a base station seldom exceeds that value. The design of the FIXSYS allows for a maximum of 10 transmitter channels at any base station. Similar histograms of the calls-on distribution for the FIXSYS are presented in Fig. 18a and b.

7.2 *Nonuniform Call-Attempts*

The data presented to this point were produced under the assumption that the spatial distribution of call-attempts is uniform. It is reasonable to expect that variations in call-attempt rates might occur

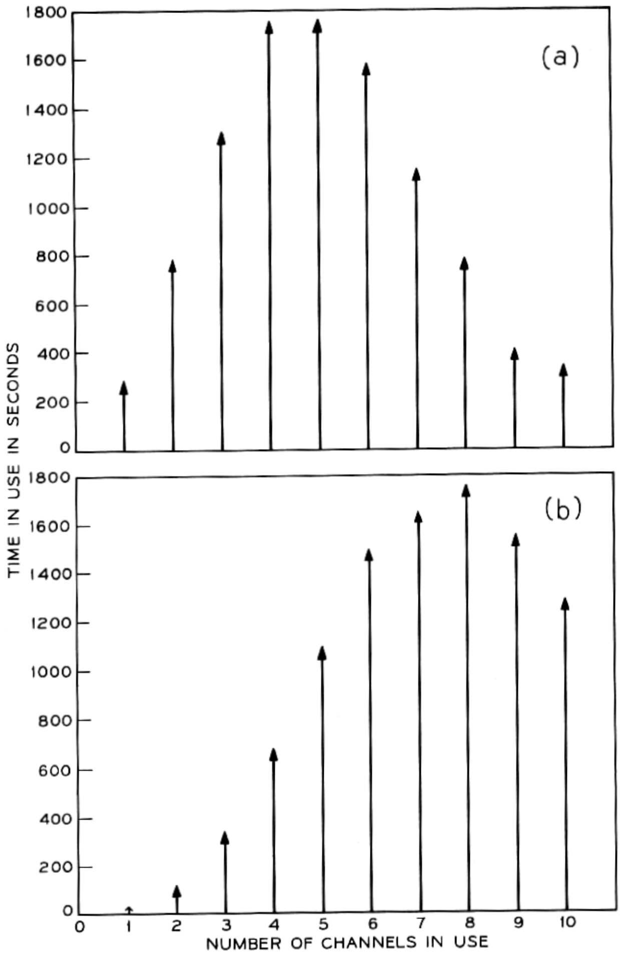
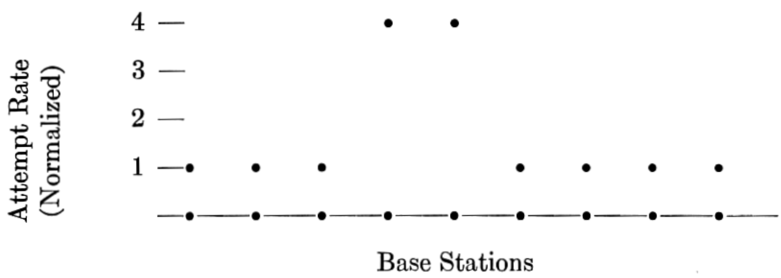


Fig. 18a—Histogram of channel usage per base station for fixed-channel assignment system with a calls-on average of 5.1.

Fig. 18b—Histogram of channel usage per base station for fixed-channel assignment with a calls-on average of 7.08.

during rush hours and there certainly will exist random occurrences of highly localized demands.

The following example is presented as a plausible situation to demonstrate the reactions of the two systems. Assume that the call-attempt density within the coverage area of two adjacent base stations is four times higher than the other base stations in the system as illustrated below:



Such a situation could occur when traffic converges at the center of a city during the morning rush hours.

One can calculate the blocking versus calls-on for the FIXSYS using the trunking formulas referenced earlier. The comparative performance of the DYNSYS was obtained by simulation. The values plotted in Fig. 19 are averages taken over one reuse interval (four base stations) centered on the two base stations with higher call-attempt rate. Since the same 1,000 system cycles were used in the simulation and the averages could not be taken over all base stations, the accuracy of the DYNSYS points is degraded compared to those presented

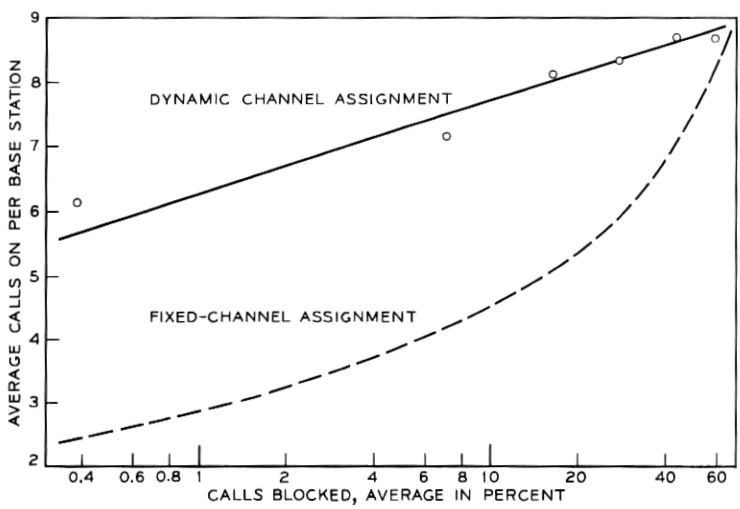


Fig. 19—Channel usage (peaked loading).

in the flat loading examples in Fig. 15. However, since there is such a marked difference in performance between the two systems more precise calculations of the points were not felt necessary. In this example, we see that the FIXSYS can handle only 40 percent of its average capacity of 10 calls "on" per base station, while maintaining 10 percent blockage, whereas the DYNSYS can work up to 70 percent capacity at the same 10-percent blockage level.

VIII. SUMMARY

The simulations described readily produce system performance parameters which are difficult, if not impossible, to obtain analytically. The system driving routine provides flexibility in parameter variation such as in demand profiles and distributions of call durations. Many channel assignment philosophies and system configurations can be readily explored by the versatile system operating routines. The graphical techniques used to display system operation for each system cycle provide a vivid picture of system dynamics.

The simulated points for uniform spatial distributions of attempts were averaged over a time sufficient to minimize statistical fluctuations. This is illustrated by the close fit of the points to the smooth curves. The fact that the simulated data for the fixed-channel assignment system agrees closely with calculations based on telephone trunking formulas lends credibility to the simulations and to the use of these formulas for determining the performance of such systems.

Portions of the system control routines such as the channel assignment procedures and the method of coding vehicle channel and base station assignments could be used essentially without modification for controlling an actual high-capacity mobile radio system.

When operating with a uniform spatial distribution of attempts and with the fixed-channel assignment system optimally matched to this distribution, the dynamic channel assignment system out-performs the fixed system for blocking rates less than 10 percent. In fact, at a blocking rate of 3 percent, the dynamic system handles 20 percent more calls per base station than the fixed system.

IX. ACKNOWLEDGMENT

The authors would like to express their appreciation to Mrs. Diane Vitello for running the computer programs and helping with program debugging.

REFERENCES

1. Schulte, H., Jr., and Cornell, W. A., "Multiarea Mobile Telephone System," IRE Trans. Veh. Commun. *9* (1960), pp. 49–53.
2. Schiff, L., "Traffic Capacity of Three Types of Common-User Mobile Radio Communication Systems," IEEE Trans. Commun. Tech., *COM-18,* No. 1 (February 1970), pp. 12–21.
3. Frenkiel, R. H., "A High-Capacity Mobile Radiotelephone System Model Using A Coordinated Small-Zone Approach," IEEE Trans. Veh. Tech., *VT-19,* No. 2 (May 1970), pp. 173–177.
4. Cox, D. C., and Reudink, D. O., "Floating Cells—A Dynamic Approach to High-Capacity Mobile Radio Systems," unpublished memorandum.