When fully operational, AUTOVON—*a worldwide network for "hot-line" situations as well as routine use—will provide instant contact among over 1700 Defense Department locations, as typified by the Air Defense Command Post shown above.*

AUTOVON switching centers are interconnected by a unique trunking arrangement. This, along with a new routing control scheme, enhances the survivability of a worldwide communications system that will be useful for normal traffic and indispensable in emergencies.

The Polygrid Network for AUTOVON

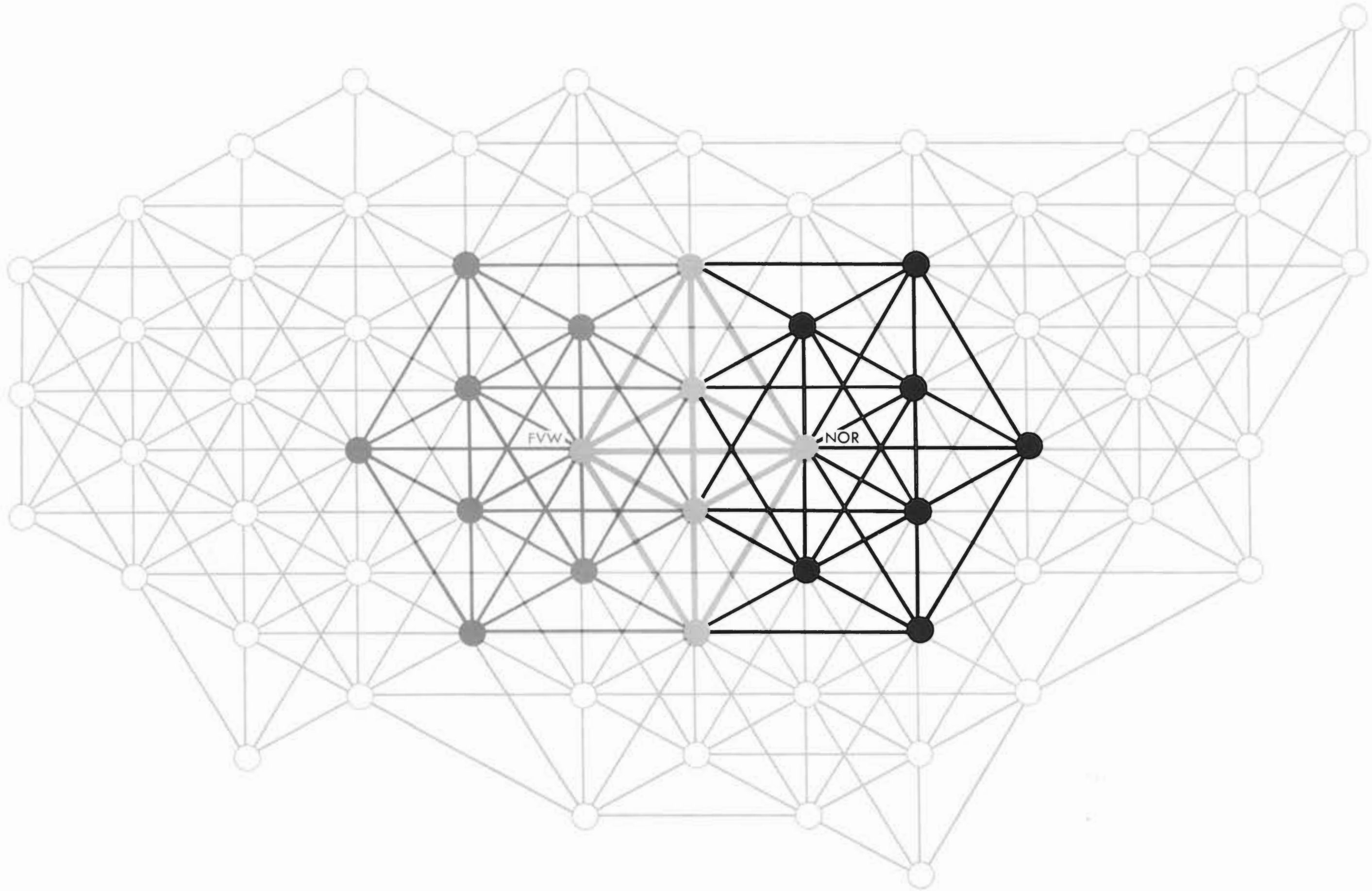
J. W. Gorgas

AUTOVON (AUTOmatic VOice Network), administered by the Defense Communications Agency of the Department of Defense, is an important part of a new worldwide defense communications system (see AUTOVON—*Switching Network for Global Defense,* RECORD, *April 1968*). Development of AUTOVON was aimed primarily at achieving the best possible switched telecommunications system using existing communications technology. However, since the overriding objective of AUTOVON is that it must survive and function even in the event of widespread or severe damage, new ways of enhancing system survivability had to be devised. To meet this objective, Bell Laboratories helped to develop a new routing control scheme and a unique network configuration called "polygrid."

Polygrid, which is based on a concept suggested by A.T.&T's L. W. Helke, is a pattern of interconnecting trunks spreading across the continental United States. The network may include up to 75 four-wire switching centers. Each center is interconnected with a multiplicity of other centers by separate trunking paths. A computer-generated alternate routing plan selects the shortest paths wherever possible to make efficient use of the system. Even under unfavorable conditions, no more than seven links in tandem (between switching centers) are used on the longest connections, so that high-quality transmission performance is achieved.

The automatic switching centers for AUTOVON serve much the same function as the telephone company commercial central offices, providing originating and terminating connections for all users, and interconnecting with a number of trunks to other switching centers. A sophisticated alternate routing system provides automatic rerouting of precedence traffic in case of partial failure or overload conditions.

All switching centers in a polygrid network are of equal rank. That is, there is no hierarchical structure (as there is in the commercial telephone system) in which the lower-ranked centers are largely dependent on the higher-ranked centers for long-haul communications. If this type of trunk configuration were used for military communications, the higher-ranked centers would constitute an attractive set of targets for an enemy to attack since their loss would severely disrupt communications. For the same reason, the number of lines and trunks at any single center is usually limited to only a few hundred, whereas in a conventional commercial system this



Interconnected switching centers form a hexagonally ordered pattern of AUTOVON *trunks across the continental United States. Defined for each switching center in the polygrid network is its own "home grid," consisting of interconnected surrounding centers which provide alternate paths to that center. Shown in green is a typical home grid arrangement for the center,* FVW. *Notice that each surrounding center is directly connected to* FVW, *as well as to most of the other surrounding centers. The home grid for* NOR *(in black), although functionally separate, physically overlaps the home grid for* FVW.

number would be more like a few thousand.

The polygrid system actually consists of two networks, one superimposed on the other. First, a *basic network* forms a geometrically ordered pattern of interconnected switching centers and furnishes short- and medium-length connectivity. Then, to minimize the number of links required for long-haul calls, a *long-haul network* is superimposed on the basic network. After various geometrical patterns were investigated, an overlapping hexagonal pattern was selected for interconnecting switching centers in the basic network (see illustration on page 224). This pattern allows traffic routing that fully exploits all available transmission paths.

When used as an element in the basic network, the hexagonal pattern can readily be extended in any direction to form a grid of any size; it lends itself to growth in small or large increments; and it can be used in an array having any desired proportion. The latter characteristic is evident in the array for the continental United States, in which the basic grid extends over a long range from east to west and a relatively short range from north to south.

One further characteristic of the hexagonal pattern is that it inherently forms *home grids* for each destination switching center, that is, each center serving a called party. A home grid can be defined as a set of switching centers surrounding, and directly connected to, a destination switching center. The hexagonal pattern provides a large number of alternate routes for calls arriving at any one of the surrounding centers.

Each destination center has its own home grid. The home grids are functionally discrete, even though they may overlap and share a number of centers in common (as shown in the illustration on page 224). The geometrical pattern for home grids is usually identical for all destination switching centers, except for peripherally located centers, which have truncated patterns.

The disciplined geometrical arrangement of the polygrid network means that network capabilities can be analyzed easily, that most trunking problems can be handled routinely, and that a relatively uniform routing plan can be applied throughout the network. Another important advantage in using a consistent geometrical pattern is that it allows the network configuration and routing doctrine to be most readily perceived and understood. Too many deviations from the established pattern would make it exceedingly difficult to plan and control the network for very long. For this reason, deviations from the standard pattern are held to a minimum.

The basic network furnishes enough paths for short- and medium-distance traffic and covers, without too many links on a call, about half of the continental United States. To minimize the number of links required on long-haul calls, an additional system of long-haul trunks is required.

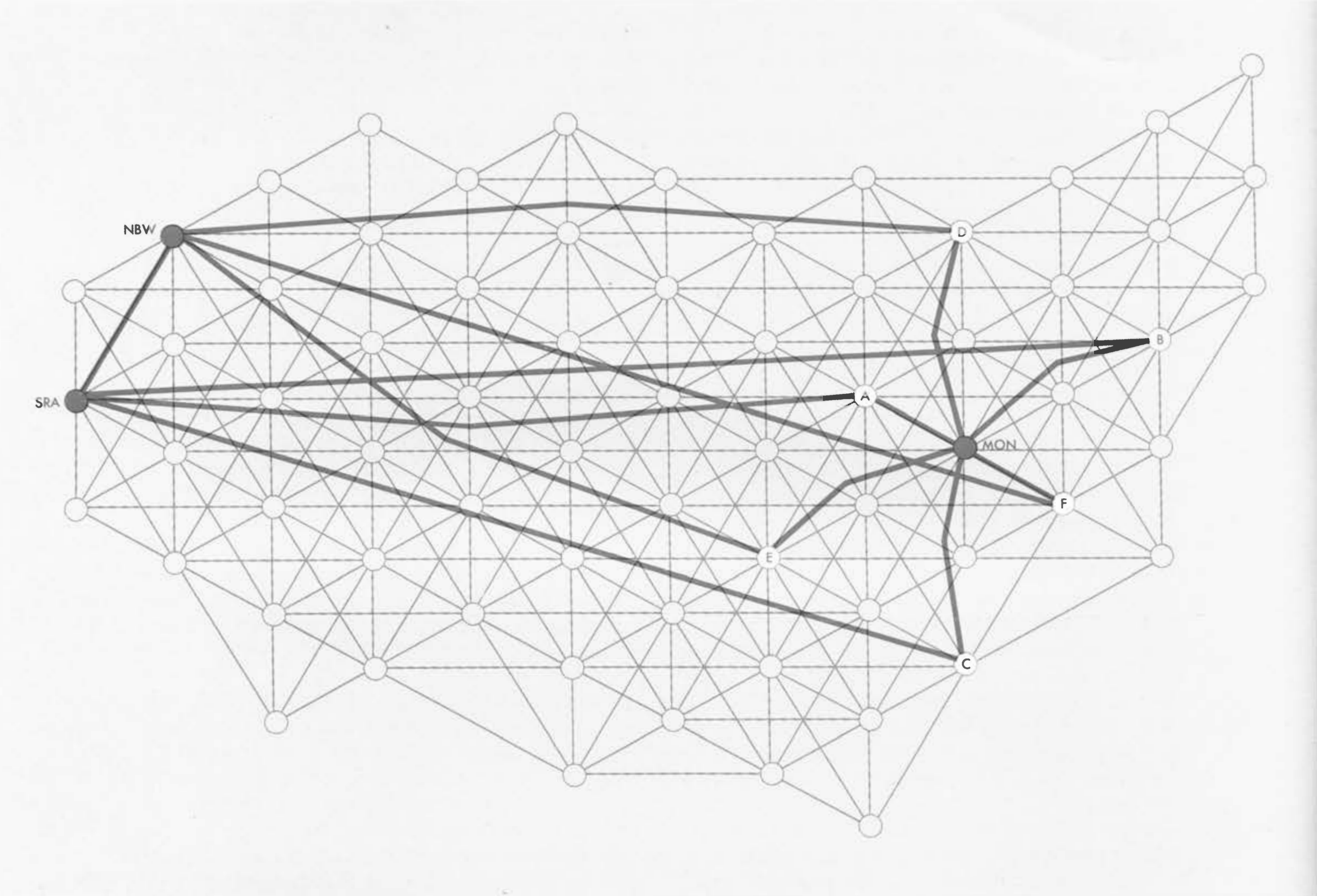
Under present engineering methods, after the pattern of home grids is established, a pattern of long-haul trunk groups radiating from an originating switching center toward distant centers is superimposed on the basic network, one center at a time, to see what long-haul trunks should be provided. The resulting arrangement provides long-haul trunks for reaching points beyond the practical range of the basic network. Normally, all centers within a two- or three-link radius of the originating center can be served adequately by the basic network. For a call going beyond the radius of the basic network, the system is so designed that there will be at least three long-haul trunk groups from the originating center to switching centers located beyond the practical reach of the basic network.

Having determined the basic and long-haul trunking patterns, it is most important to build the trunk groups along widely dispersed routes. This will enhance survivability by preventing the facilities and their nodal points from becoming, in themselves, prime targets. Computer programs are being devised for this function as well as for other complex network synthesis functions. Some of these programs, such as one for sizing trunk groups, are already in use.

A sophisticated alternate routing plan has been developed for operation with the polygrid network. A principal objective of this routing plan is to ensure that important calls will be completed when switching centers along the normal route are tied up with higher precedence calls or have been destroyed. This objective is being met. At the same time, the more routine, day-to-day traffic is handled efficiently.

The first principle in polygrid route control is to make a distinction between forward and lateral routing. A call routed into a home grid from an exterior center has employed "forward routing." Also, a call routed from one exterior center to another has employed forward routing if it advances toward the destination by a specified distance improvement factor. A "back-haul" distance factor must also be specified to prohibit the routing of calls to any center located farther from the destination than this back-haul factor permits. All acceptable routes not identified as forward routes are called lateral routes.

In the polygrid network, actual routing of a



If a call to MON *is originated at* SRA, *three forward long-haul routes are available. These routes go to centers (designated above as* A, B, *and* C) *which are connected directly to* MON. *If all three routes are in use and cannot be preempted, then a lateral route, to* NBW, *for example, may be available. In this case, three forward long-haul trunks are provided between* NBW *and three other centers (designated* D, E, *and* F) *which connect directly with* MON. *If the direct routes from these points are busy and cannot be seized, other paths can be used.*

call is controlled by automatic switching equipment at each switching center. When the user dials a call, the switching equipment automatically triggers a programmed instruction that determines which route the call will take, based on the precedence of the call, its destination, and the congestion on the programmed routes. Each instruction is coded by a number called the "route control digit." This inter-office signal, transmitted over the trunks, does three things: it exercises automatic control over alternate routing at the next switching center; it prevents "shuttle" (back-and-forth routing) or "ring-around-the-rosie" (call returning to an office via another office); and it helps limit the number of trunk links which may be used on a call by allowing only two successive lateral routings.

The specific route control digits (or "RC" digits) and what they mean are shown on this page. Successive lateral routings are limited to two by the use of RC "1" or RC "2" on the first lateral route, and RC "3" on the second lateral route. The programming of RC "3" prevents the automatic switching system from selecting a third successive lateral route. In each case, if the preferred route is not open and cannot be seized, the program automatically calls for the next best alternate route, and the call progresses until limited by an RC "3," something which would rarely occur on a high-precedence call. To promote network efficiency, only one lateral link is permitted on a routine (nonpreemptive) call. Two lateral links are permitted on a high-precedence call. (For a discussion of call priorities, see AUTOVON—*Switching Network for Global Defense*, RECORD, *April 1968*.)

Some idea of the routing plan is indicated by the trunking involved on a call from the center at Santa Rosa, California (SRA) to the center at Monrovia, Maryland (MON). (See the illustration on page 226.) In this more or less typical case, polygrid routing permits SRA to be programmed for routing calls to MON over nine different trunk groups (ten, if there is also a long-haul trunk group direct to MON). The nine groups are arranged in three "triples." The preferred triple consists of forward routes to centers located in or near the home grid of MON. If a trunk in one of these forward routes is available, it will be selected and the call will be advanced with RC "0" indicating that the next center can use all programmed routes.

If there is no route available in the first triple and the call has preemptive capabilities, the call will preempt a lower precedence call and be advanced. If, however, the call is unable to preempt

RC DIGIT	MEANING
0	Employ all programmed routes.
1	Employ forward route(s) plus first choice lateral routes.
2	Employ forward route(s) plus second choice lateral routes.
3	Employ forward routes only.

Throughout the AUTOVON *network, automatic switching equipment routes a call according to programmed instructions. These instructions are coded by route control digits, as defined above.*

because the other calls have equal or higher precedence, an alternate route must be selected, and either RC "1" or RC "2" must be forwarded to the next center, whichever will assure that the call will not shuttle back. If, for example, a lateral alternate route to the center at North Bend, Washington (NBW) is selected, the first-choice routes would again be a triple of forward routes, but this time to other centers which are also located in or near the home grid for the destination center (MON).

From a switching center in the home grid, there is always, by definition, a direct trunk group to the destination center. Again, if a direct trunk is not open and cannot be seized, alternate lateral routes to centers within the home grid can be selected. Typically, six lateral routes within each home grid are programmed. RC "1" or RC "2" would be used on the first lateral and, if it should be necessary to make a second lateral alternate routing, RC "3" would be used to bring alternate routing to a halt.

The capability of polygrid routing to circumvent damaged or badly overloaded routes is by now readily apparent. From the labyrinth of routes which are available on a precedence call, one might get the impression that the network operates inefficiently using too many links. This is not so, however. The routing principles are applied so that the most direct routes are selected most often. At the same time, a precedence call can be snaked through any one of a very large number of paths if necessary.

The polygrid network plays a major role in the survivability of AUTOVON. Along with its other virtues of flexibility and economy, polygrid represents the best method that technology can now offer for the rapid and reliable connecting of defense communications.